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ISSUED IN THREE PARTS

PART I. GENERAL (*Monthly*) PART II. POWER ENGINEERING (*Alternate Months*)
PART III. COMMUNICATION ENGINEERING (*Quarterly*)

PART I. GENERAL

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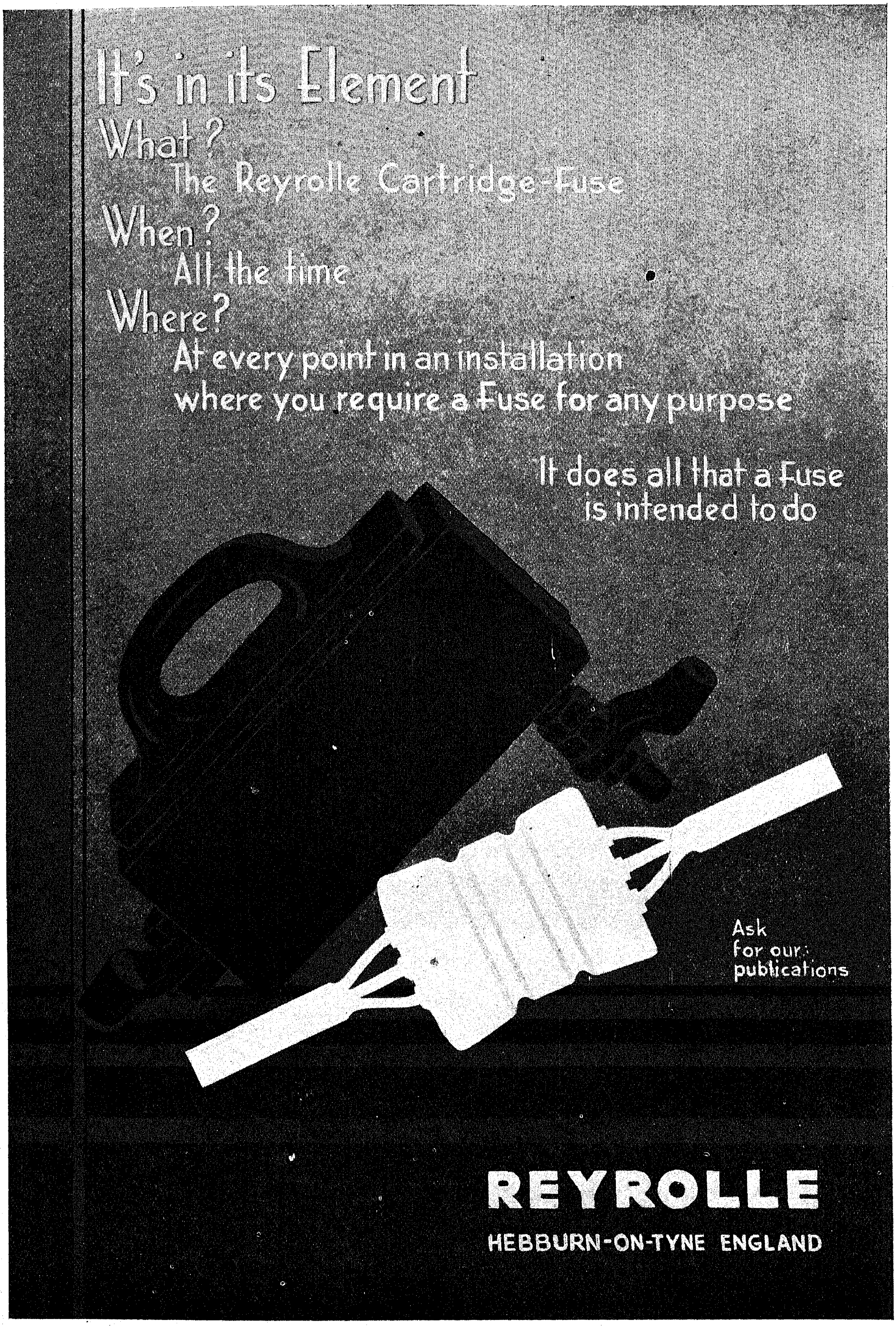

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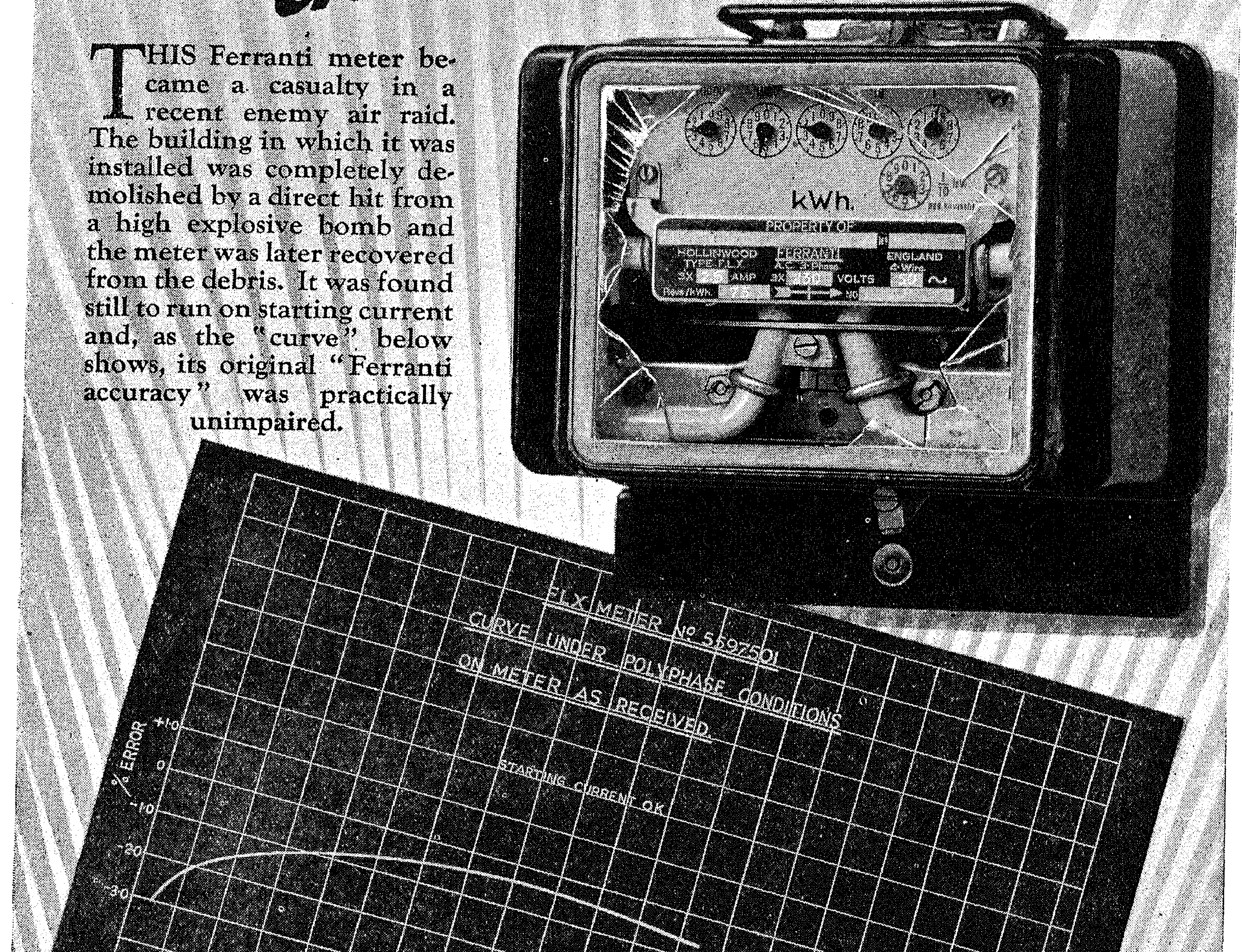

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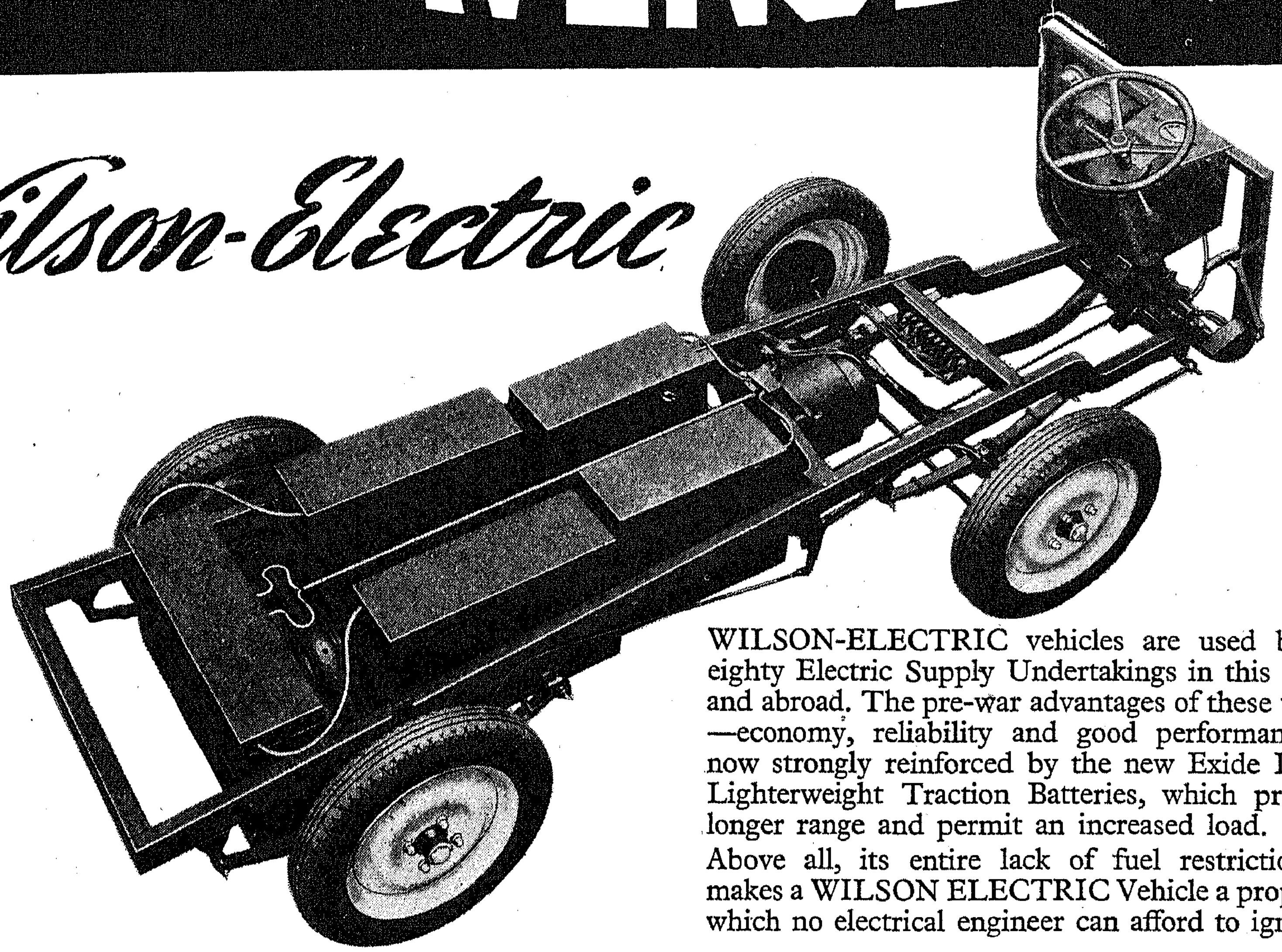

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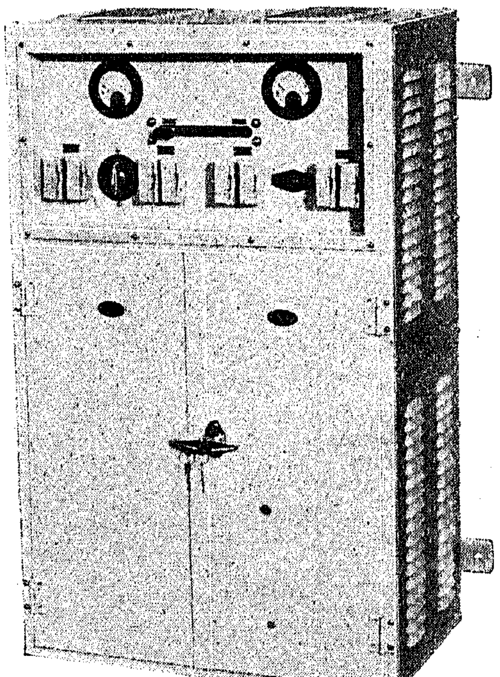

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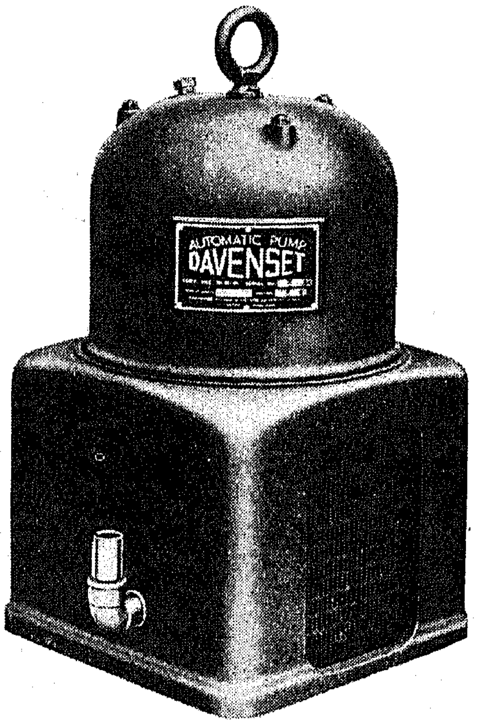

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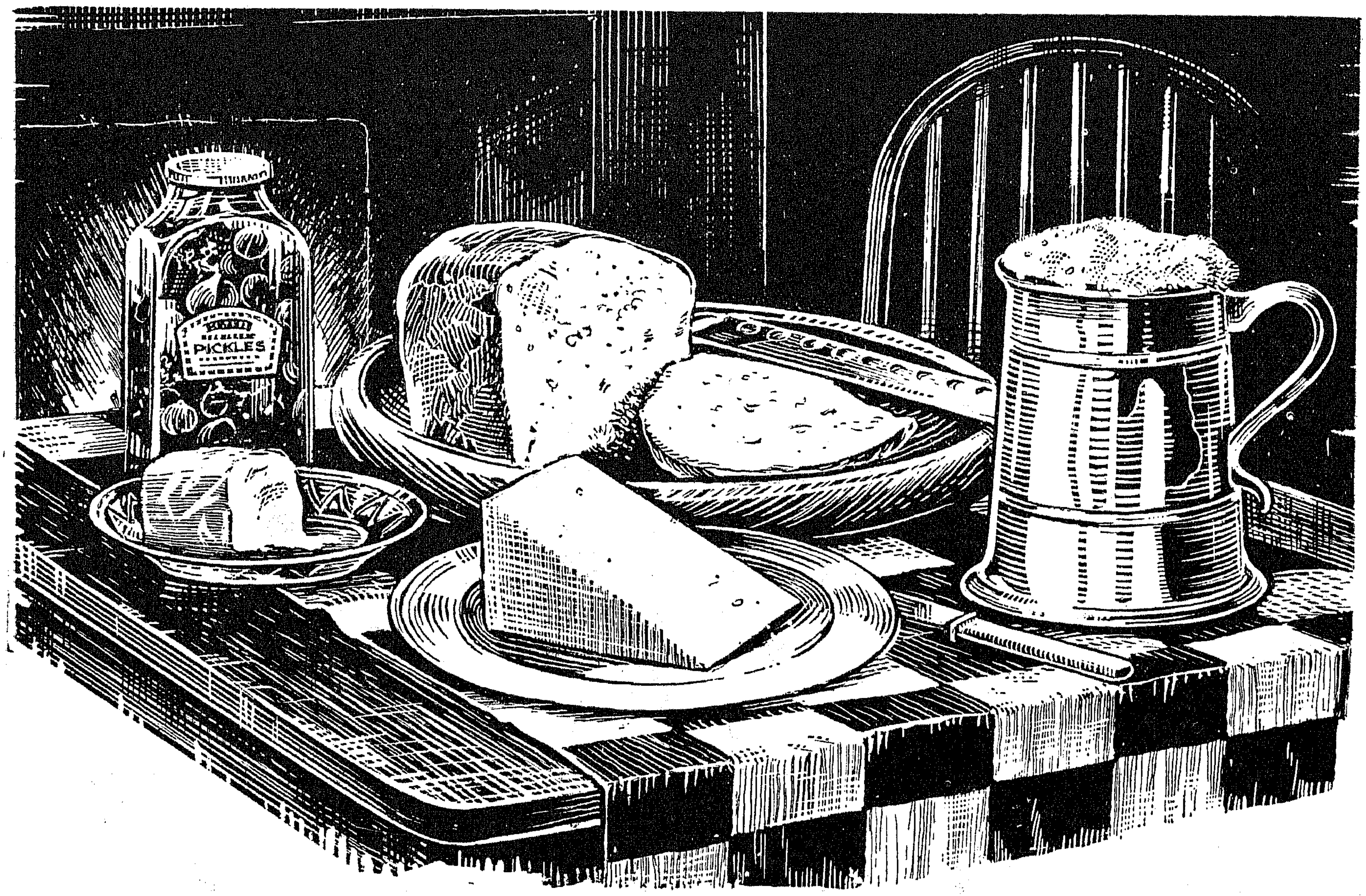

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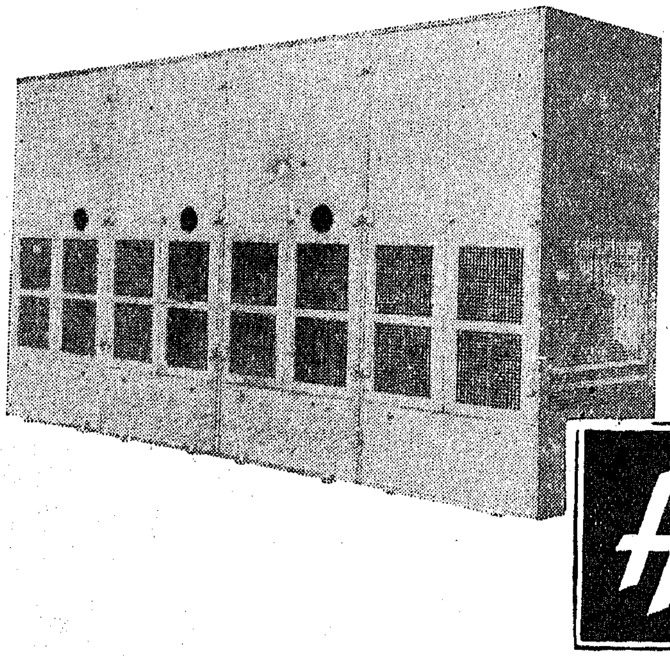

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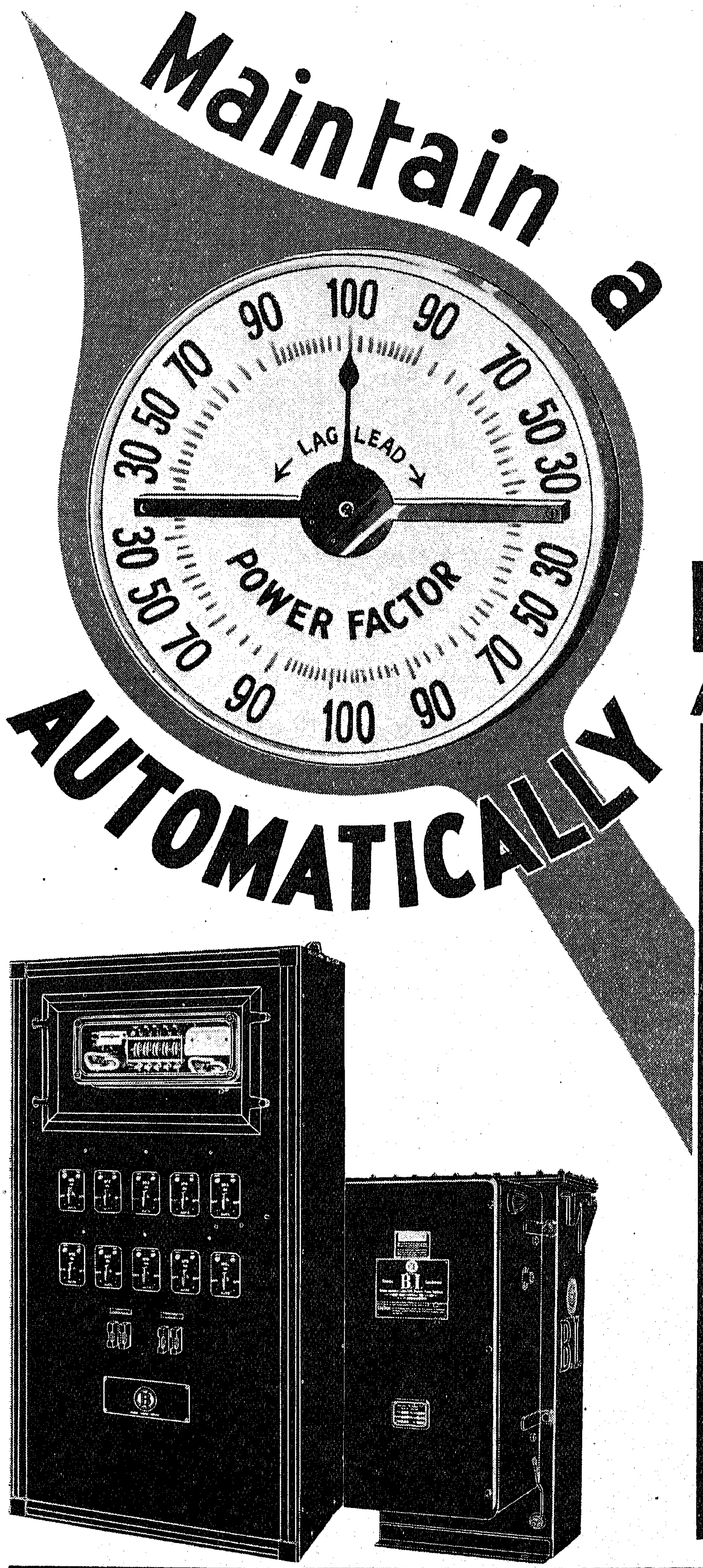

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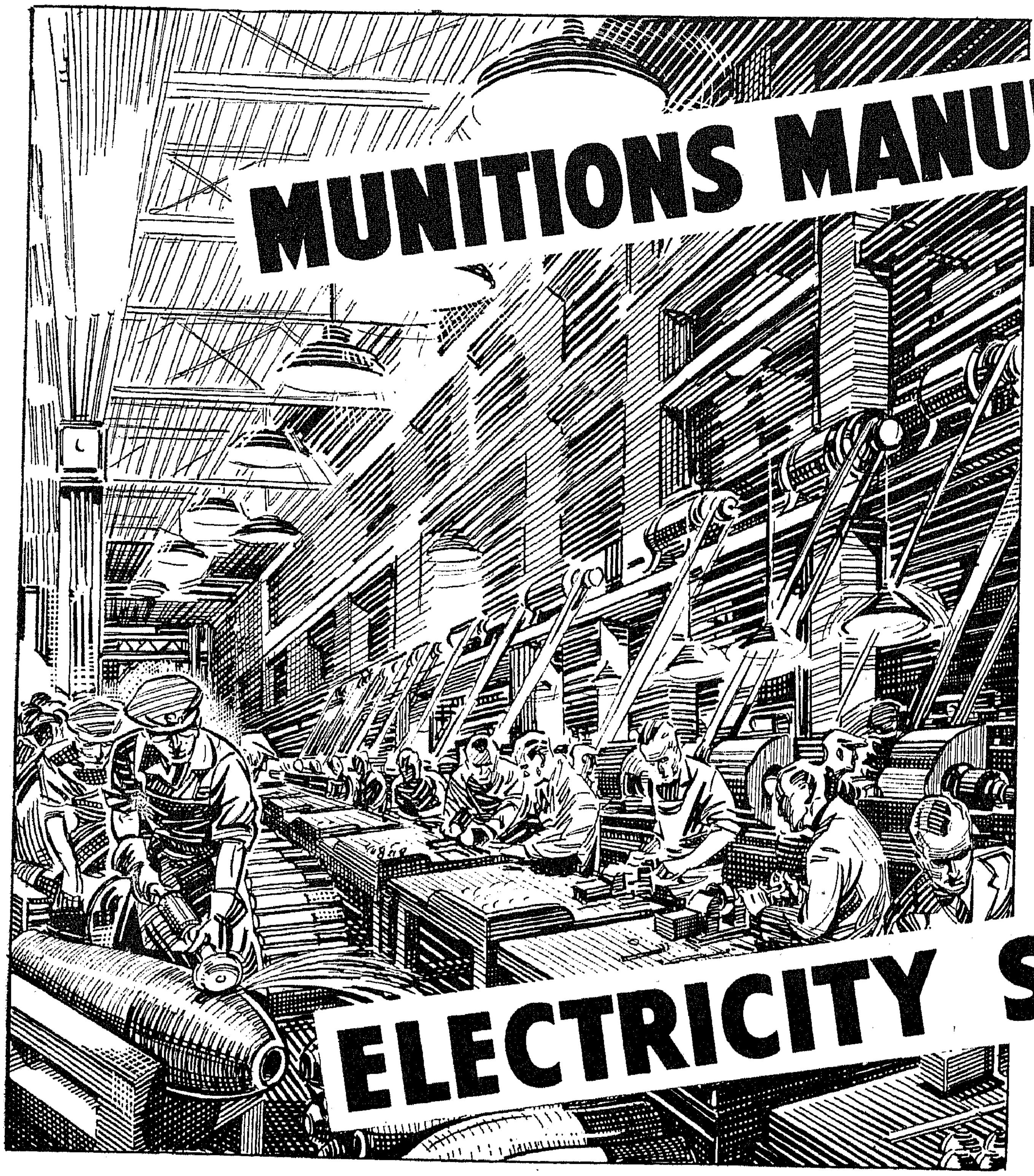

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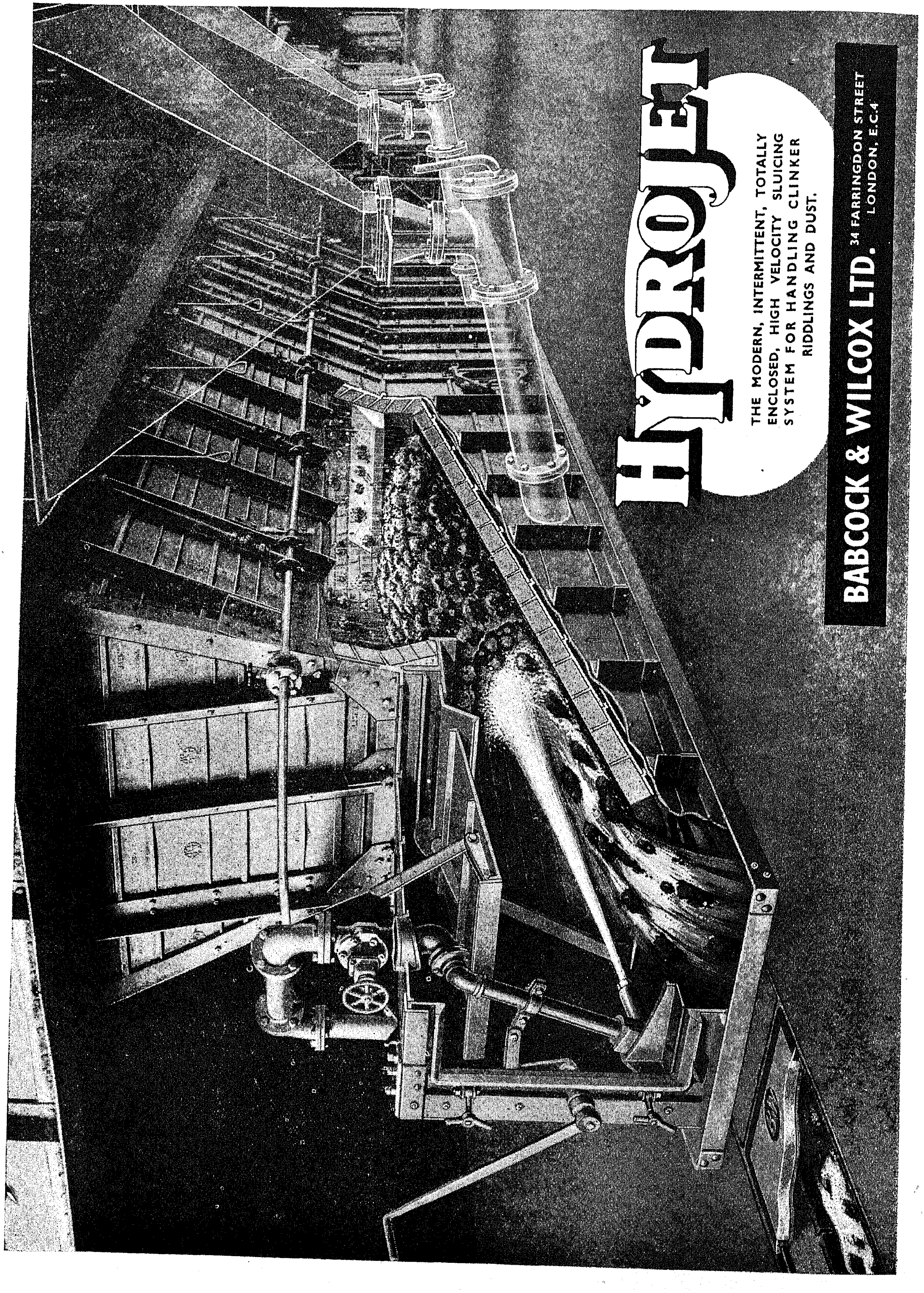

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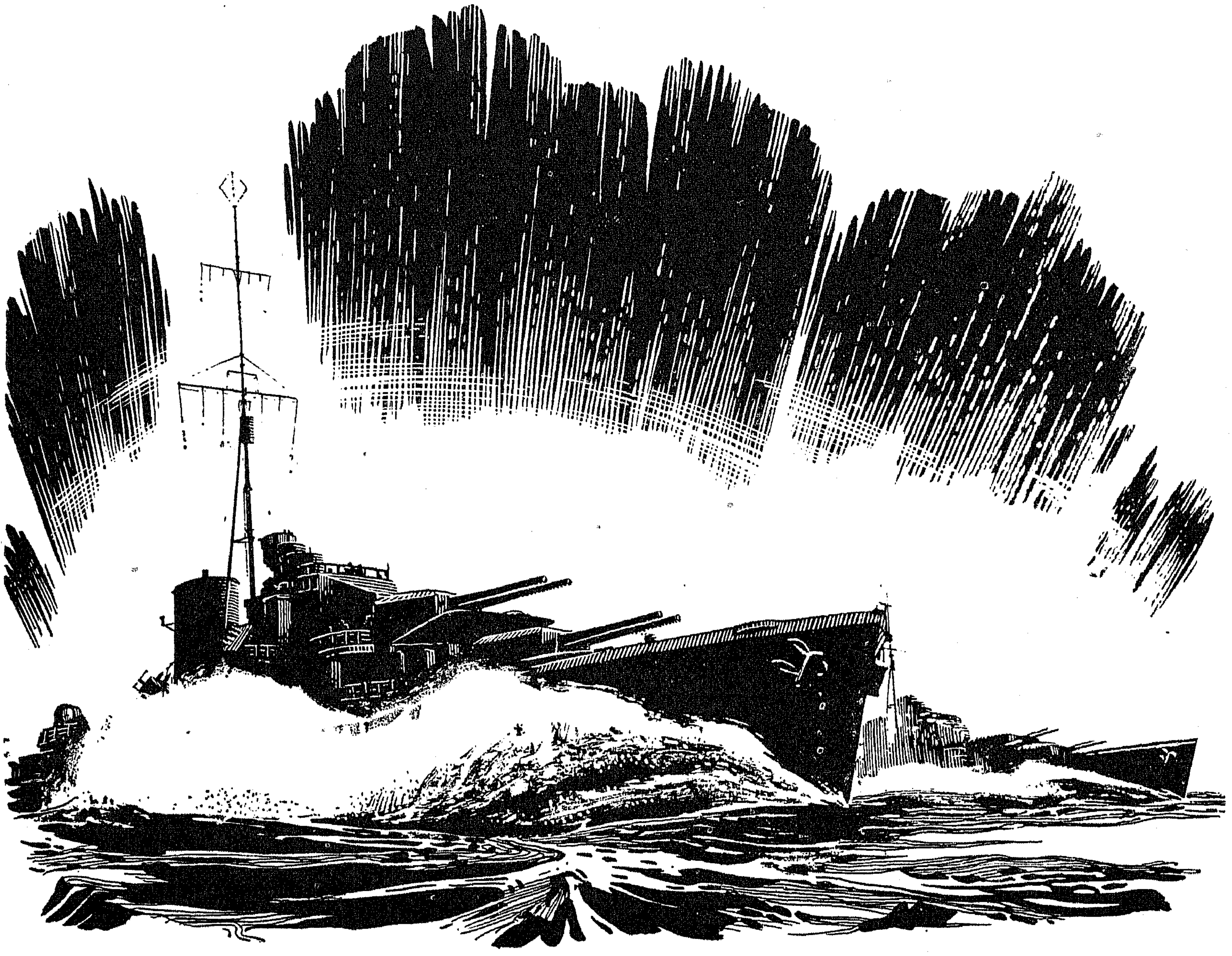

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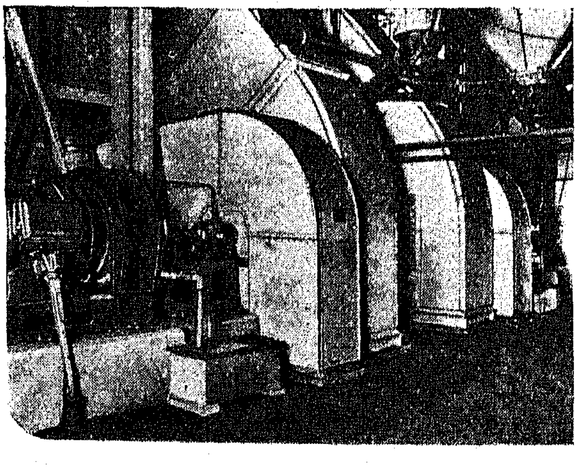

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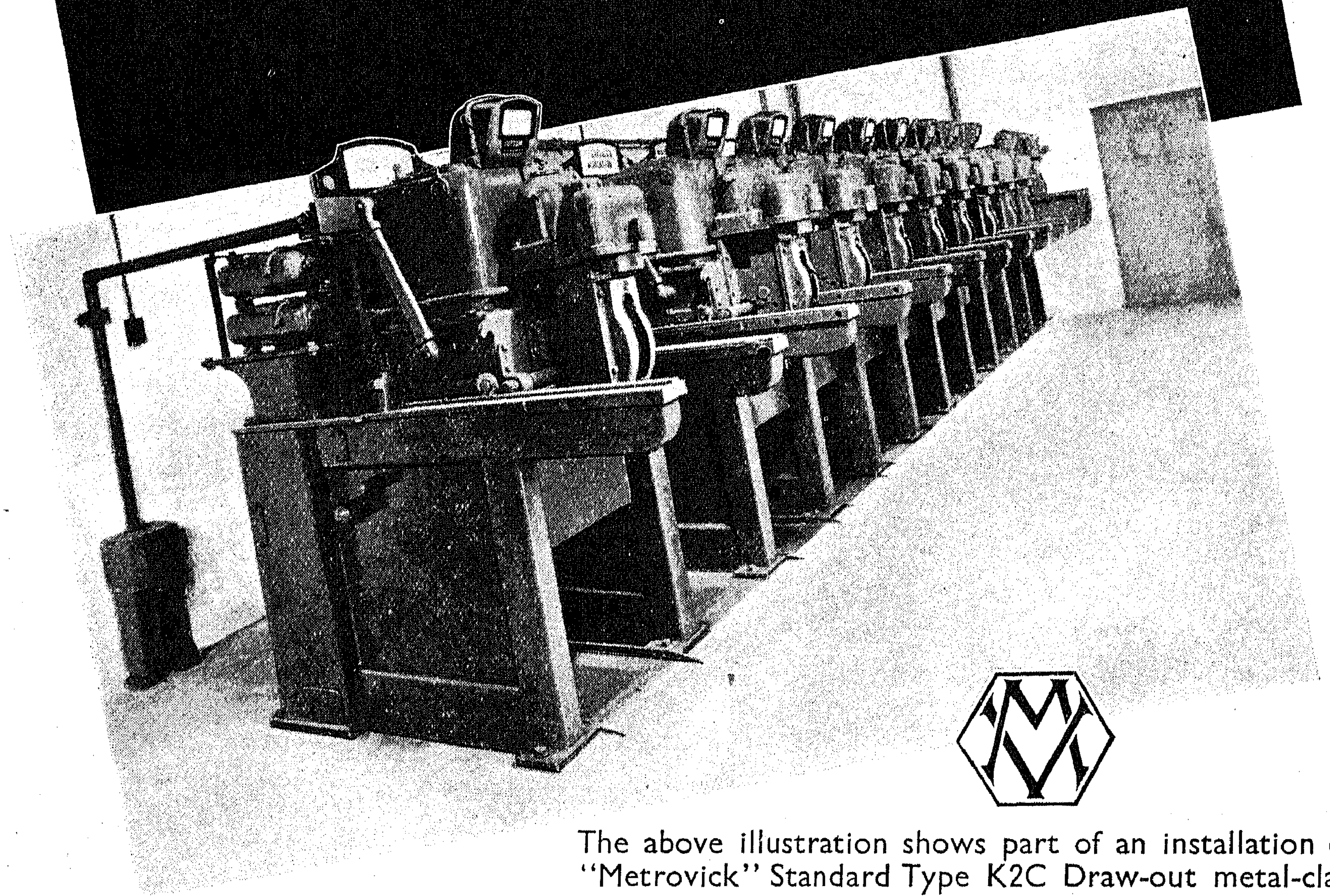

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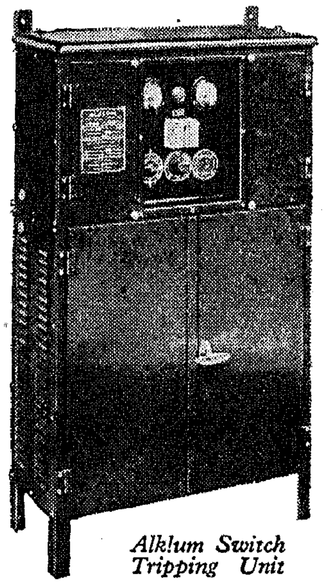

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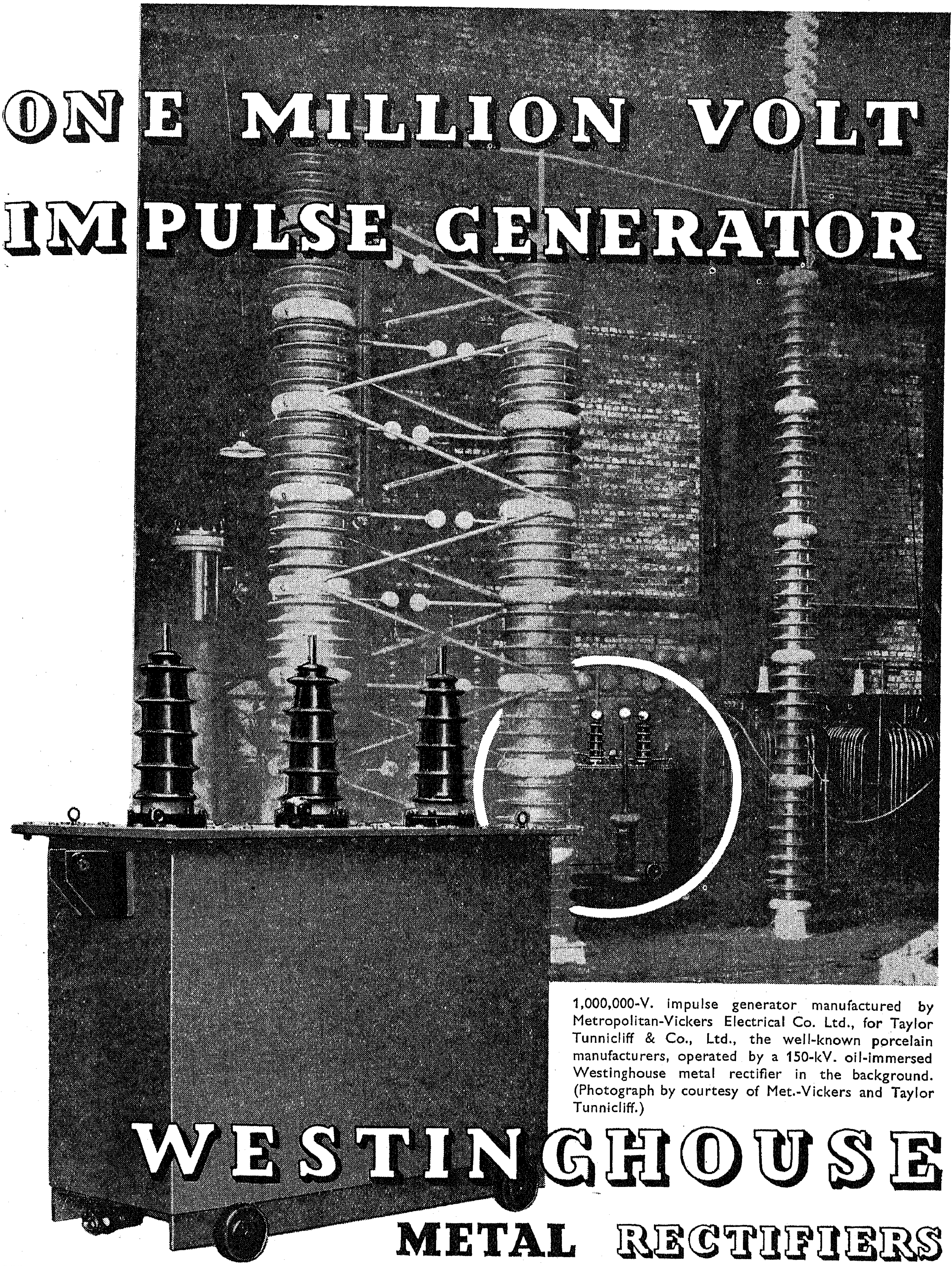

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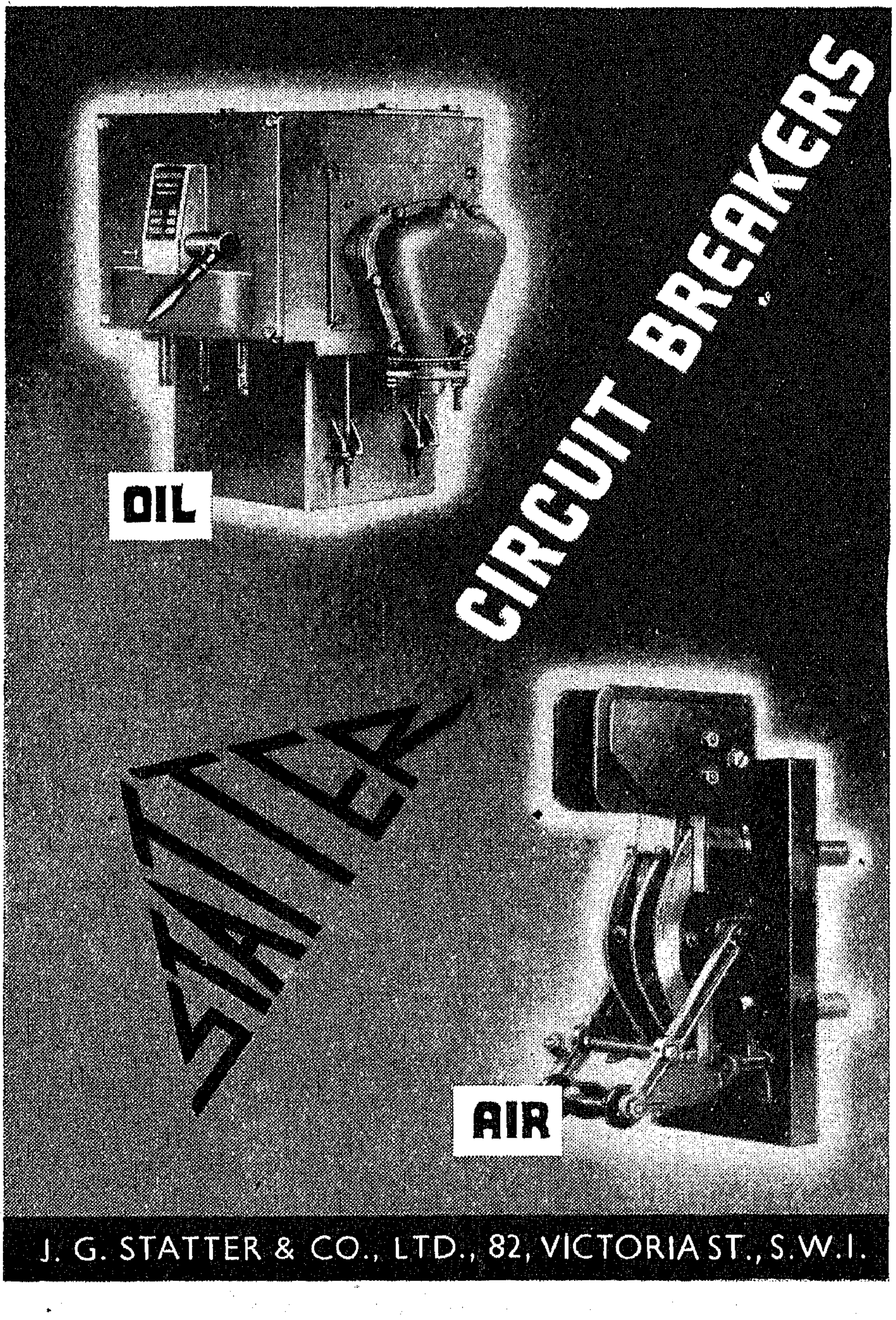

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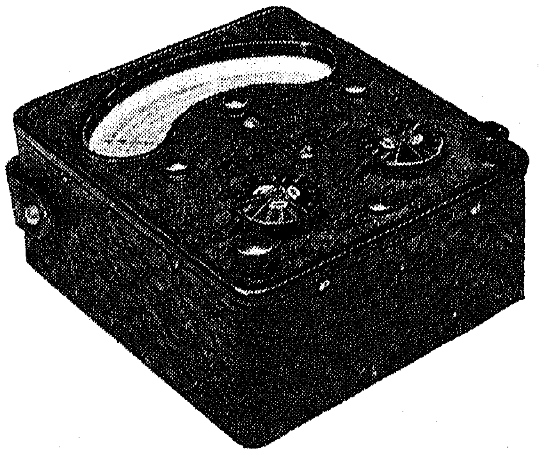

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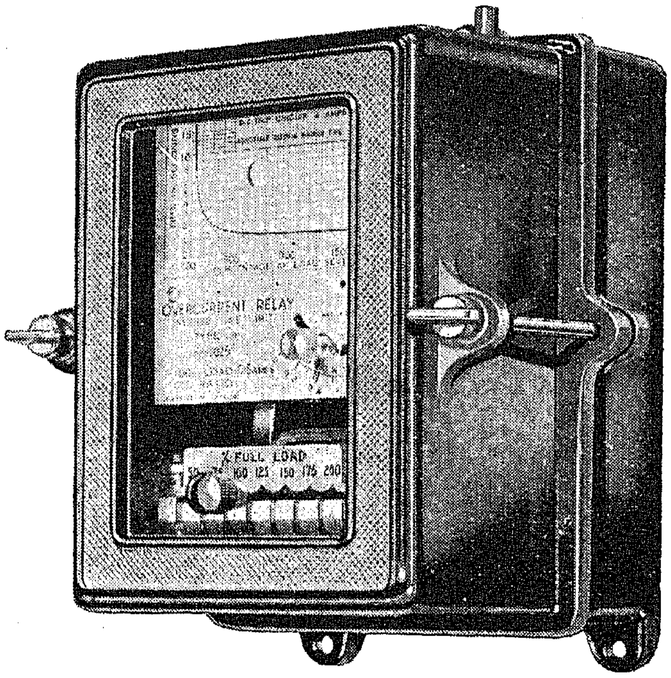

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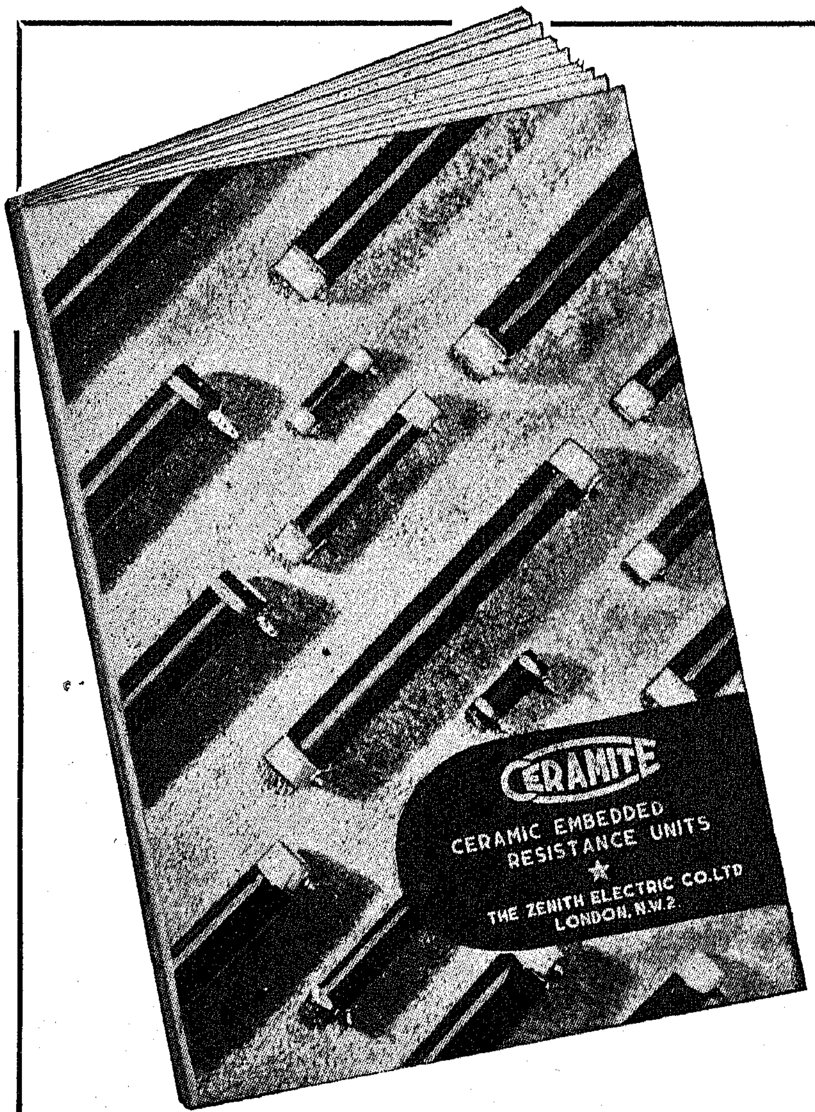
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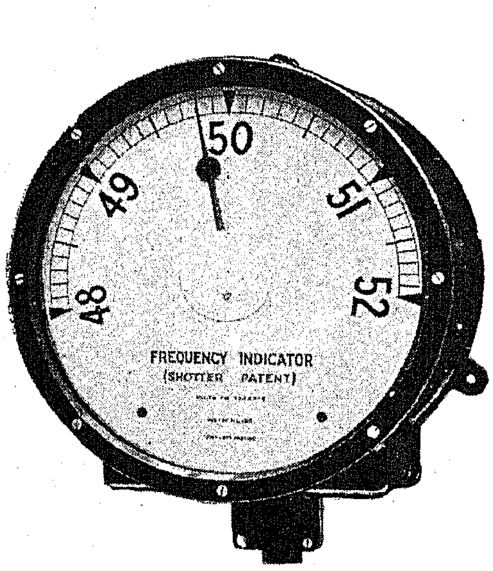

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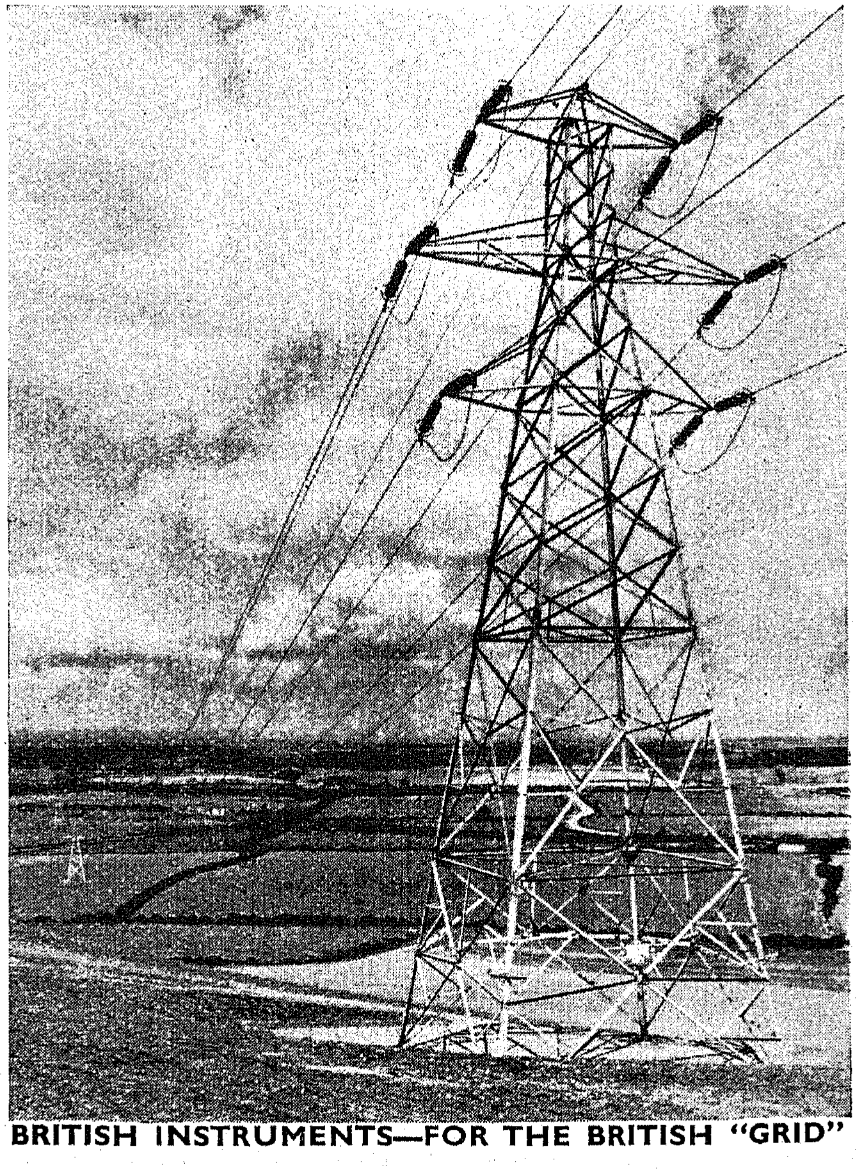

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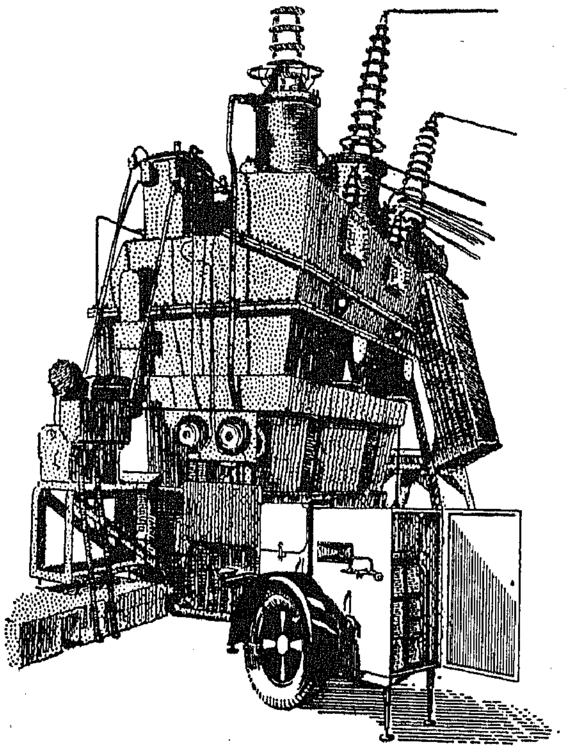

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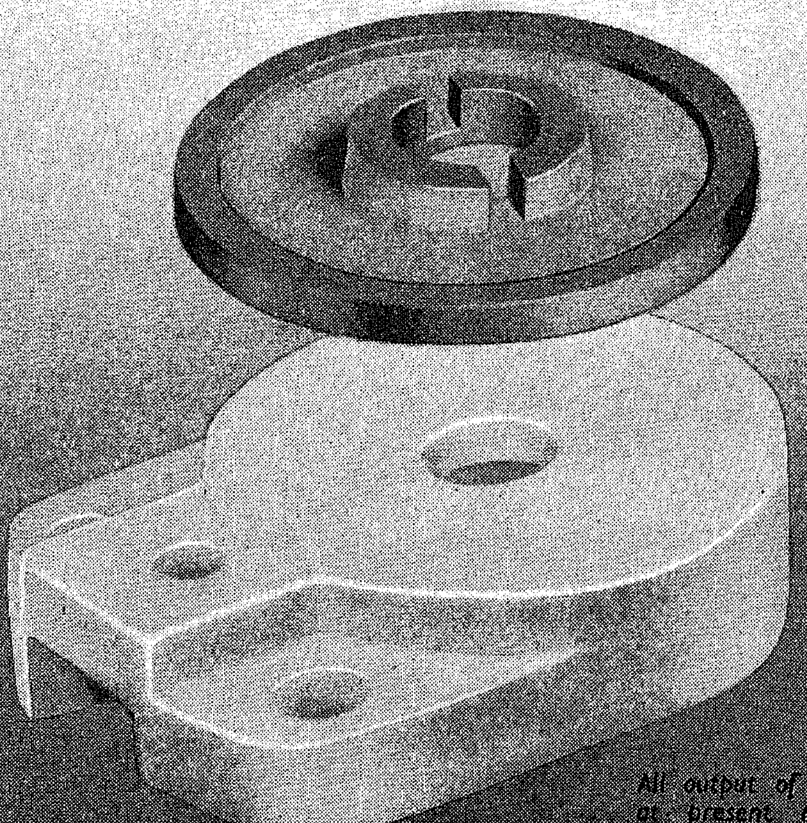

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THE JOURNAL OF THE INSTITUTION OF ELECTRICAL ENGINEERS

EDITED BY W. K. BRASHER, SECRETARY

VOL. 88. PART I (GENERAL), No. 4. APRIL 1941

CONTRIBUTIONS TO DISCUSSIONS ON INSTITUTION PAPERS

Among the inconveniences to which a considerable proportion of the members of The Institution have been subjected through the indiscriminate warfare waged by our enemies and through the pressure of the work on which they are engaged, is the loss of contact with their fellow members, owing to the temporary cancellation of the customary social functions and meetings in London and at a number of the Local Centres and Sub-Centres. The meetings, which in normal times are held for the formal discussion of papers, provide opportunities for the informal interchange of experiences before the reading of the paper and after the discussion is concluded.

The printed report of a discussion lacks the atmosphere of the meeting and must necessarily—especially in these days of restricted supplies of paper—be considerably condensed and shorn of most of its personal appeal. The absence of lantern slides, demonstrations and blackboard sketches contributes to emphasize the loss of personal contact with the author. Moreover, the author's oral reply at the meeting to points made or questions asked by speakers is of current interest to many of those present at the meeting, and the same purpose may not be served so adequately by his communicated reply some months later in the *Journal.*

Nevertheless, the printed report of a discussion, although published some time after the meeting, frequently contains information no less valuable than that in the paper itself. At the present time, while the customary meetings cannot be held for the reading and discussion of papers, it is particularly desirable that all members who are in a position to present useful comment on a paper should place such information at the disposal of their fellow members by contributing written communications to the discussion for publication in the *Journal* with the author's reply.

In the history of our great Institution there are many occasions on which the discussion of a paper has opened new fields of research or pointed new methods of application. We take a certain degree of pride in not allowing the conditions under which we work to-day to blind us to the need for preventing too great a break in progress in the scientific fields that we cover. Under the impetus of war conditions, progress in many directions in the past year has been remarkable, but, unfortunately, there are many of these developments which, although they will probably provide material for a number of papers and communications for publication in the *Journal* after the war, cannot at the present time be discussed in public. This must, however, be a strong reason for dealing as fully as possible with those matters the publication of which is permissible and desirable.

The preparation and writing of a paper is no mean task at any time; under war conditions all the more credit is due to those public-spirited members who have undertaken this task and placed their knowledge so unstintingly at the disposal of their fellows. It will show an appreciation of this spirit if those members who are in a position to contribute to the store of knowledge on the subject of a paper would put their ideas for further progress, and their views on the investigation or method under discussion, on record together with the paper so that they may not be lost entirely.

On page 140 of Institution Notes in this issue will be found a list of those papers which were to have been read during the present session and the discussion on which is still open.

INSTITUTION NOTES

ROLL OF HONOUR
(FIFTH LIST)*

Killed in Action.

Adam, Lieutenant D.	Royal Engineers	Associate
Ord, Sub-Lieut. C. B.	Royal Naval Volunteer Reserve	Student
Pyman, Pilot Officer L. L.	Royal Air Force	Student
Ryan, Lieut.-Comdr. R. J. H.	Royal Navy	Associate Member
Stockton, Sergeant D. A.	Royal Air Force	Graduate
Tozer, Pilot Officer J. J.	Royal Air Force	Student
Tuck, Lieutenant W. D.	Royal Artillery	Associate Member

Killed on Active Service.

Armstrong, Act. Ldg. Naval Airman A.	Fleet Air Arm	Student
Gates, Signalman R. E.	Royal Signals	Graduate
Prout, Sergeant R.W.	Royal New Zealand Air Force	Student
Raymond, Mechanist Sergt.-Major I. V.	Royal Engineers	Graduate

Died on Active Service.

Brewis, Lieut.-Col. J. M., M.C.	Royal Army Ordnance Corps	Associate Member

Died of Wounds.

Rothwell, Signalman H. K.	Royal Signals	Student

HONOURS AND DISTINCTIONS CONFERRED ON MEMBERS
(FOURTH LIST)†

George Cross.

Ryan, Lieut.-Comdr. R. J. H.	Royal Navy	Associate Member

D.F.C.

Gore, Flying Officer W. E.	Royal Air Force (Since reported missing)	Graduate

M.C.

Metson, Lieutenant G. H.	Royal Signals	Associate Member

George Medal.

Duncan, Sub-Lieut. R. A.	Royal Naval Volunteer Reserve	Graduate

Mentioned in Despatches.

Furnell, Lieutenant P. G.	Royal Naval Volunteer Reserve	Associate Member
Stewart, Lieutenant A. C.	Royal Naval Volunteer Reserve	Student

Civilian Awards

M.B.E.

Daw, Sydney Ernest H. (Associate).

George Medal.

Griffiths, Gilbert John (Associate Member).
Little, Gilbert Joseph S. (Member).

ENGINEERING JOINT COUNCIL

The I.E.E. Council have renominated Dr. A. P. M. Fleming, C.B.E., M.Sc., and Mr. H. T. Young to serve with the President *(ex officio)* as the representatives of The Institution on the Engineering Joint Council.

INSTITUTION MEETINGS, THURSDAY, 8th MAY, 1941

The following meetings will be held in The Institution Lecture Theatre, Savoy Place, Victoria Embankment, London, W.C.2, on the above date:—

Ordinary Meeting, at 2.30 p.m.*
(Kelvin Lecture)

The Thirty-Second Kelvin Lecture will be delivered by Dr. S. Chapman, F.R.S., who will take as his subject "Electrical Works by Helios, or The Sun and the Ionosphere."

At the commencement of this meeting the Sir John Kennedy Medal of The Engineering Institute of Canada will, at the request of the Institute, be presented by the President (Mr. J. R. Beard, M.Sc.) to Lieut.-General A. G. L. McNaughton, C.B., C.M.G., D.S.O., Commander of the Canadian Forces in Great Britain (Associate Member). This Medal is awarded "for contributions to the advancement of Engineering Science."

The President will also present the Faraday Medal awarded by The Institution to Dr. A. P. M. Fleming, C.B.E., M.Sc. (Past-President), for the year 1941, and the Coopers Hill War Memorial Prize and Medal to Mr. John S. Forrest, M.A. (Associate Member), for the paper submitted by him in the competition for the triennial award which fell to The Institution in 1940.

Annual General Meeting, at 3.45 p.m.*
(Corporate Members and Associates only)

To receive and consider the Accounts for the year ended 31st December, 1940, and the Annual Report of the Council, and to elect Auditors.

Copies of the Accounts and Report (which will in due course be published in the *Journal*) can be obtained from the Secretary of The Institution about 10 days before the date of the meeting.

Benevolent Fund Annual General Meeting
(of Contributors to the Fund)
at approximately 4.30 p.m., after the conclusion of the I.E.E. Annual General Meeting

To receive and consider the Accounts for the year ended 31st December, 1940, and the Annual Report of the Committee of Management, and to elect an Honorary Auditor.

Copies of the Accounts and Report (which will in due course be published in the *Journal*) can be obtained from the Secretary of The Institution about 10 days before the date of the meeting.

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* See *Journal I.E.E.*, 86, p. 510, and 87, pp. 110, 351 and 695.

† See *Journal I.E.E.*, 86, p. 510, and 87, pp. 351 and 695.

* The times of these Meetings have been revised since the preliminary announcement in the January issue of the *Journal* (Part I).

WESTERN AUSTRALIA LOCAL COMMITTEE

The Council have confirmed the appointment by the above Committee of Mr. J. B. Jukes (Associate Member) as Honorary Secretary of the Committee.

LOCAL CENTRE ACTIVITIES

Mersey and North Wales (Liverpool) Centre.

The following is a review of the activities of the Centre during the session:—

As a result of the conditions last autumn it was felt that evening meetings were not advisable, but it was decided to try the experiment of holding the opening meeting on a Saturday afternoon. This took place on the 2nd November, when Mr. J. E. Nelson delivered his Chairman's Address entitled "The Electric Supply Industry." The Address was repeated on Saturday afternoon, 7th December, at Chester, for the benefit of the large membership there and in North Wales who, especially under the prevailing conditions, find it difficult to get to Liverpool for meetings. The attendance at both these meetings was disappointing and showed that Saturday afternoon meetings were not a solution of the problem. Accordingly it was decided to defer meetings until they could be held at an early hour on the usual evening, namely Monday.

The first of these evening meetings took place on Monday, 3rd March, and the attendance was encouraging, being almost as large as in normal times when the paper is one of sectional appeal. The paper read and discussed was on "The High-rupturing-capacity Cartridge Fuse, with special reference to Short-Circuit Performance," by Mr. J. W. Gibson, M.Eng.

At the next meeting, on Monday, 17th March, Mr. Sinclair read his paper entitled "The Trolleybus."

The Annual General Meeting, followed by three or four short papers by local members, will be held on Monday, 21st April, and a further meeting is contemplated—to be held at Chester some time in May, when a Transmission Section paper will be read and discussed.

The Faraday Lecture is usually very well attended in Liverpool, but under present conditions it was reluctantly decided not to hold the Lecture this session.

The Students' Section have experienced considerable difficulty this session. First, a large number of Students have joined the Services or have been drafted elsewhere on Government work. Secondly, meetings arranged for Saturday afternoons or at an early hour on a weekday evening are not convenient to the junior members. In these circumstances only two meetings have been held. The first, on Saturday, 26th October, was an "Open Discussion" on three or four subjects. At the second meeting, on Saturday afternoon, 8th March, Mr. F. B. Atkinson, B.Eng., Chairman of the Students' Section, delivered his Address entitled "The Pendulum Electric Clock," and there was a fairly good attendance.

A third meeting, the Annual General Meeting, has been arranged for Saturday afternoon, 3rd May, when it is hoped that a paper will also be read and discussed, failing which short papers will be invited.

North-Eastern Centre (and Tees-Side Sub-Centre).

At the meeting of the Sub-Centre on the 5th March a discussion took place on "Electricity in Agriculture." The discussion was introduced by Mr. H. W. Grimmitt, and Mr. C. A. Cameron Brown replied to the various points raised by the speakers.

North-Western Centre.

At the meeting on the 22nd February Mr. W. J. Mason read the paper on "Electricity in Paper Mills" written by himself and Mr. S. A. G. Emms. The meeting was attended by members of the Technical Section of the Paper Makers Association, as well as by members of the Mersey and North Wales (Liverpool) Centre.

The meeting on the 22nd March was a joint one with The Institution of Post Office Electrical Engineers. This joint meeting is an annual arrangement, the two Institutions taking it in turn to provide the paper. This year it is the turn of the Post Office Electrical Engineers, and the paper presented was by Mr. R. M. Chamney, B.Sc., and was entitled "Some Aspects of Line Construction."

The Students' Section continues to carry out a full programme, and arranged for the usual Students' Dance to be held on Saturday, 29th March, from 3 p.m. to 8 p.m. at Old Trafford.

Mr. Guthrie Jones has resigned the Chairmanship of the Students' Section on taking up a Government appointment, and Mr. W. Wallwork has been appointed in his stead.

Scottish Centre (and Dundee Sub-Centre).

The meeting of the Scottish Centre on the 11th March was held jointly with the Students' Section and the Post Office Engineers, and the attendance was 158. An informal paper on "The Glasgow Automatic Telephone System" was presented by Major H. A. Ashdowne of the G.P.O. staff. It was of particular interest to local members as the system had just been introduced into a number of Glasgow exchanges. The paper was illustrated by lantern slides, and recordings were given of the various audible notes in use with the system. An interesting discussion followed.

Western Centre [and the West Wales (Swansea) and Devon and Cornwall Sub-Centres].

In place of the Annual Dinner a Luncheon was arranged by the Committee of the Western Centre and took place at Bristol on the 10th February, under the chairmanship of Mr. H. R. Beasant. The function was very well attended and proved a great success. Among the guests were the President (Mr. J. R. Beard, M.Sc.), the Lord Mayor and Lady Mayoress of Bristol, the Chairman of the Bristol Electricity Committee, and the Secretary of The Institution (Mr. W. K. Brasher, B.A.). It was followed by a meeting at which Mr. Schiller's paper entitled "The Control of the Domestic Load" was read by Mr. J. I. Bernard on behalf of the author. The paper gave rise to an interesting discussion.

The next meeting of the Centre was held at Cardiff on Monday, 10th March, when Mr. S. W. Melsom read his paper entitled "Electric Cables and Fire Risks: Recent Developments and Investigations."

The Centre has suffered a great loss by the death of its Honorary Secretary, Mr. G. L. Coventon, Associate Member, which occurred at Gloucester on the 23rd February after a short illness of 5 days. He took office at the commencement of the 1938–39 session and carried out his secretarial duties with the highest efficiency; his cheerful disposition also endeared him to all with whom he came in contact. His early days were spent with the India-rubber, Gutta Percha and Telegraph Works Co., at Silvertown. Later he was resident engineer of the Chepstow Electric Light and Power Co., transferring in 1929 to the West Gloucestershire Power Co. He severed his connection with that company last year, when he went into business on his own account.

CONTRIBUTIONS TO DISCUSSIONS

As it has been found inadvisable to hold meetings of The Institution in London this session for the reading and discussion of papers, the Council will welcome the submission of written comments on the papers that would normally have been read, with a view to the publication of such comments as a discussion, with the authors' replies, when the papers themselves are published in due course.

The following is a list of the papers that were to have been read during the session and of which a limited number of advance copies is available. It is hoped that, in view of the necessity of economizing the Institution's restricted supply of paper, members will only apply for copies of those papers to the discussion of which they would wish to contribute.

Author	*Title of Paper, and Part of the Journal in which it will appear*
H. W. Grimmitt	"Electricity in Agriculture." (An introduction to a written discussion on the subject) (Part II)
C. A. Mason, B.Sc.(Eng.) and J. Moir	"Acoustics of Cinema Auditoria" (Part III)
A. J. King, B.Sc.Tech., R. W. Guelke, Ph.D., C. R. Maguire, B.Sc., and R. A. Scott, Ph.D.	"An Objective Noise-Meter Reading in Phons for Sustained Noises, with special reference to Engineering Plant" (Part II)
T. C. Gilbert	"Voltage-operated Earth-leakage Protection" (Part II)
C. F. Booth	"The Application and Use of Quartz Crystals in Telecommunications" (Part III)
J. C. Chaston, Ph.D.	"Materials for Electrical Contacts" (Part II)
N. M. Rust, O. E. Keall, J. F. Ramsay, M.A., and K. R. Sturley, Ph.D.	"Broadcast Receivers: A Review" (Part III)
W. J. Mason and S. A. G. Emms, B.Sc.	"Electricity in Paper Mills" (Part II)
B. J. Edwards	"The Design of Television Receiving Apparatus" (Part III)
Alwyn Evans	"The Electricity Supply (Meters) Act, 1936—its Legal and Technical Implications" (Part II)
W. A. Cook, B.Sc.(Eng.)	"Outdoor Bushings—their Construction, Testing and Standardization" (Part II)
P. Schiller	"The Control of the Domestic Load" (Part II)
F. C. Williams, D.Sc., D.Phil.	"The Fluctuations of Space-charge-limited Currents in Diodes" (Part III)
C. E. R. Bruce, M.A., B.Sc., and R. H. Golde	"The Lightning Discharge" (Part II)
A. Fairweather, M.Sc., and J. Ingham, M.Sc.	"Subsistence Transients in Circuits containing a Non-linear Resistor, with reference to the Problem of Spark-quenching" (Part I)

In addition, the following paper has been accepted by the Transmission Section Committee as suitable for discussion. Advance copies of the paper will be ready before the end of April:—

J. W. Leach	"Standardization of Distribution in Densely Loaded Areas" (Part II)

BOOKS REQUIRED FOR VOCATIONAL TRAINING COURSES FOR THOSE IN HIS MAJESTY'S FORCES

Members will be aware that The Institution is collaborating with the War Office and the Board of Education in formulating courses of instruction in electrical engineering subjects for those temporarily serving in His Majesty's Forces. Certain developments have resulted in difficulty in obtaining copies of one of the textbooks on which the course in telecommunication has been based, and if any member can release a copy of "Telegraphy and Telephony, including Wireless," by E. Mallett, either on loan or as a gift, the Secretary will ensure that it reaches the correct quarter.

BRITISH STANDARDS

The Secretary has been asked by the British Standards Institution to draw attention to the following new and revised specifications, copies of which can be obtained from the British Standards Institution, 28, Victoria Street, London, S.W.1, at the prices indicated.

Industrial Circuit-Breakers (B.S. No. 936).

It was stated in the Foreword to the 1937 edition of B.S. No. 116 (Oil Circuit-breakers) that pending the issue of a Standard Specification for industrial circuit-breakers, B.S. No. 116—1929 could be applied to such circuit-breakers for voltages below 3·3 kV. The 1929 edition of B.S. No. 116, however, was very incomplete as regards the tests to verify the rating, and it has been known for some time that a new specification was in preparation. This new specification has now been issued as B.S. No. 936—1940, and will be welcomed by all industrial users of oil circuit-breakers at voltages up to and including 660 volts. It applies to single-phase and 3-phase breakers having breaking capacities up to 44 000 amperes and intended for use in those electrically remote parts of the system where marked asymmetry in the short-circuit current cannot occur, and where the re-striking voltage conditions are not severe.

The general structure of the specification closely follows that of B.S. No. 116—1937, there being sections on rating and marking, temperature-rise, routine tests, type tests, service conditions, care and maintenance. An example of a report of a type test is given in one of the appendices, and there are other appendices dealing with the calculation of short-circuit currents and with the selection of standard oil circuit-breakers.

The price of the specification is 3s. 10d., post free.

Flexible Cords for Miners' Cap Lamps (B.S. No. 937).

The most important features in a cable for miners' cap lamps are:—

(*a*) Flexibility, coupled with resistance to damage by tension.

(*b*) Ability to withstand bending without fracture of the conductor.

(*c*) Exclusion of readily ignitable insulation or filling materials.

(*d*) Resistance of the sheath to deterioration by absorption of oil or grease.

(*e*) Maximum electrical conductance compatible with the requisite flexibility.

In drafting this specification consideration has, so far as practicable, been given to all these points.

The price of the specification is 2s. (post free 2s. 3d.).

Automobile Lamps (B.S. No. 941).

This specification has been issued at the request of the Ministry of Aircraft Production. It covers 6-volt and 12-volt bulbs for head, side and rear lamps of motor-cars and the motor-car class of goods vehicle. It is not intended to cover lamps for public service vehicles or for heavy commercial goods vehicles.

The specification has been drafted with wartime requirements and conditions in mind, and it will be revised in due course as regards some of the technical details, with a view to meeting peace-time requirements.

The price of the specification is 2s. 3d., post free.

Lighting Fittings for an Illumination of 0·002 Foot-Candle (BS/ARP 16).

There are four British Standard Specifications dealing specifically with A.R.P. lighting fittings, these being BS/ARP 16, 20, 21 and 37. These specifications each deal with a different level of illumination ranging from 0·0002 to 0·2 foot-candle.

The specification for the fittings to give an illumination of 0·002 foot-candle (BS/ARP 16) was first issued in September, 1939, and this has now been revised. It covers both gas and electric fittings primarily intended for outdoor use. Two types are specified, intended respectively for use with (i) a relatively wide spacing (minimum spacing/height ratio 4: 1) and (ii) a relatively close spacing (minimum spacing/height ratio 2: 1).

It may be recalled that in the original specification only type (i) was specified.

The particular fittings described in the specification are presented as examples of devices fulfilling the essential conditions prescribed, but other designs fulfilling these requirements may of course be adopted. Preference should in general be given to methods which achieve the desired result in the most economical manner, i.e. by using sources of low power rather than by reducing the candle-power of relatively high-power sources by obscuration.

In addition to a statement of the essential conditions to be observed and the descriptions and illustrations of the fittings given as examples, there is a useful appendix giving notes on the use of A.R.P. lighting fittings. These notes point out that where uniform illumination is desired the spacing of the units should not materially exceed the minimum mentioned in the specification. Attention should be paid to the required maintenance of fittings, mantles and lamps being replaced when deterioration is evident. Maintenance of the reflection factor, within the tolerance specified, of the interior surface of the shade is of major importance. The importance of increasing the contrast between the brightness of obstructions and their surroundings is stressed, and it is recommended that when the fittings are used at docks and at shipbuilding and ship-repairing yards and in the vicinity of water they should be so placed and screened that reflections of the sources of light in the water are eliminated as far as possible.

The data furnished in the specification afford adequate guidance in regard to installation. Results may subsequently be checked by the aid of illumination gauges, of which simple types, adapted for use at these low levels of illumination, are now available. Such gauges are covered by Specification BS/ARP 30.

The price of the specification (BS/ARP 16) is 8d., post free.

Detection of Incendiary-Bomb Fires by Heat-Sensitive Devices (BS/ARP 53).

The February issue of Part I of the *Journal* contained (see pages 88–92) a Memorandum by the I.E.E. Advisory Committee to the Ministry of Home Security, entitled "Fire-Detection Devices, with special reference to the Detection of Incendiary Bombs." A specification for one system of detection has already been published by the British Standards Institution. This specification deals with fire detectors of the heat-sensitive type and it will in due course be followed by specifications for other types of detector.

The specification is designed to ensure the reliable performance of devices which cause an electric alarm to be sounded either when the fire causes the temperature to rise to a certain value or when the temperature rapidly increases. Such devices include thermostats (temperature-operated switches) and devices which operate by virtue of the melting of an alloy or wax, or by the expansion of a liquid. The method of testing the detector is defined and notes are given on the selection, installation and maintenance of detection systems.

Copies of the specification may be obtained from the B.S.I., price 4d., post free, and copies of the Memorandum on Fire-Detection Devices either from the B.S.I. or from the I.E.E., price 6d., post free.

Electrical Heating of Shelters (BS/ARP 54).

Soon after the outbreak of war British Standard Specifications for the lighting of air-raid shelters were published. At that time the long hours during which shelters would be occupied could not be foreseen, and little attention appears to have been paid to the possible necessity of providing some artificial heating in the shelters. Experience has shown, however, that many public shelters are used as dormitories, and that some degree of artificial heating is required in order to keep the shelters comfortably aired and dry. A few local authorities have been installing electric heaters on a fairly large scale, but the majority of local authorities have probably held back pending some official guidance from the Government.

The Ministry of Health has now recognized the need for the artificial heating of shelters, and a British Standard Specification has been issued with the approval of the Ministry.

The specification is based on the requirements of a shelter built for accommodating 50 persons when seated. Such a shelter would normally accommodate between 25 and 35 bunks. Larger shelters can of course be dealt with by suitably extending the data given in the specification. The types of heater prescribed are of the convector type, including forced convection heaters, and figures are given for the watts loading for surface shelters and for underground shelters of the basement type and trench type. The position of the heaters is specified, and stress is laid on the importance of ensuring adequate ventilation. Provision is made for the installation to be controlled by a thermostat.

The price of the specification is 4d., post free.

E.R.A. REPORTS

The Secretary has been asked by the British Electrical and Allied Industries Research Association to draw attention to the following Reports which have recently been issued. Copies can be obtained from the Association, 15 Savoy Street, London, W.C.2, at the prices indicated.

E.R.A. Report Ref. W/T4: Improvement of Load Factor in Farm Grinding [By W. H. Cashmore, B.A., N.D.A. (of the Institute for Research in Agricultural Engineering, University of Oxford) and C. A. Cameron Brown, B.Sc. (of the E.R.A.)].

The Report describes experimental research directed to the improvement of the load factor of farm grinding of feeding stuffs, which has hitherto been carried out with large machines running for short periods. The poor load factor resulting therefrom has definite electrical disadvantages, but it is also of direct significance to the farmer who has to pay the cost of the mill and the motor, both being large and expensive in relation to the aggregate work done.

The experimental work has been based on the use of a small single-rotor hammer mill requiring not more than 3 h.p. and controlled by a time switch used in conjunction with a calibrated grain feeding unit, the meal being blown through a pipe line to bins situated at the best spot for disposal of the meal.

Results show such an arrangement to be eminently practicable and to offer appreciable advantages to both the supply authority and the farmer. The former is offered a load with improved load factor and of reduced maximum demand. The latter is offered distinct advantages in the lower cost of the mill and the motor, better control over grinding quality, and the facility to make use of special night-rate tariffs and concessions for low-power motors. He is also placed in a better position where the fixed charge is based on connected load or on maximum demand. There is the further national advantage that plant of the kind developed requires much less steel and other vital materials than the orthodox type of plant. Notwithstanding the small size of the unit described, it is capable of handling the grinding requirements of most farms, 3 to 4 tons per week being well within its capacity.

The Report comprises 30 pages and is freely illustrated with photographs and diagrams.

Its price is 2s. 6d. (postage 4d.).

E.R.A. Report Ref. W/T5: Electric Heating of Beehives—Preliminary Report (By E. B. Wedmore, C.B.E.).

This Report deals with preliminary experiments to bring the problem of heating of beehives into proper perspective quantitatively and from the standpoint of beekeeping, and it describes the construction and preliminary testing of certain heating units. Tests are now being made at the Rothamsted Experimental Station under working conditions on a large scale.

The price of the Report is 3s. 6d. (postage 3d.).

MEMBERS ON SERVICE WITH H.M. FORCES (EIGHTH LIST)*

(NOTE.—The Secretary will be glad to receive, for publication in subsequent lists, the names of other members of The Institution who are serving with His Majesty's Forces, together with particulars of their rank and the unit in which they are serving. A Roll of Honour, and lists of honours awarded, promotions, transfers, etc., are also being published from time to time.)

Members

Name	*Corps, etc.*	*Rank*
Gleadle-Richards, E. M.	Royal Signals	Major
Humphreys, P. H. I.	Royal Engineers	Lieutenant
Leak, B. W.	Royal Engineers	Major
Unwin, D. J.	Royal Army Ordnance Corps	Lieutenant

Associate Members

Bader, E.	Royal Engineers	Lieut.-Col.
Banister, F. E. L.	Royal Engineers	Captain
Barker, R. H.	3rd Cavalry (Indian)	Lieutenant
Beale, S. J. M.	Royal Engineers	Lieutenant
Bourne, H.	Royal Engineers	Lieutenant
Bradley, J. F.	Royal Engineers	Sec. Lieut.
Brown, E. F.	Royal Naval Volunteer Reserve	Lieutenant
Coles, R. V.	Royal Signals	Lieutenant
Crofton, R. D.	Royal Air Force	Flying Officer
Dalton, J. C.	Royal Signals	Hon. Colonel
Dennis, L. A.	Royal Artillery	Sergeant
Fawsett, F. A. B.	Royal Air Force	Flt.-Lieut.
Fisher, A.	Royal Naval Volunteer Reserve	Lieutenant
Flynn, G. H. R.	Royal Signals	Lieutenant
Galbraith, R. A. H.	Royal Canadian Corps of Signals	Lieut.-Col.
Garrity, H. A.	Royal Air Force	Flt.-Lieut.
Gilbert, T. C.	Royal Engineers	Sec. Lieut.
Gilchrist, J.	Royal Navy	Lieutenant
Goatley, A. H.	Royal Navy	Lieut.-Comdr.
Gullan, A. G.	Royal Engineers	Major
Hitt, D. G.	Royal Engineers	Captain
Horley, F. A.	Royal Air Force	Flt.-Lieut.
Irwin, C. K.	Royal Army Service Corps	Sec. Lieut.
Jackson, J. G.	Royal Naval Volunteer Reserve	Lieutenant
Jubb, B.	Indian Army Ordnance Corps	Captain
Kennedy, E. J.	Royal Signals	Captain
Lavinton, E.	Royal Air Force	Pilot Officer
Lawrence, C. W.	Royal Air Force	Pilot Officer
Lepper, G. H.	Royal Signals	Lieutenant
Linton, A. H. F.	Royal Naval Volunteer Reserve	Lieutenant
Longfield, J. F.	Royal Signals	Major
Martin, G. H. R.	Royal Naval Volunteer Reserve	Lieutenant
Melio, L. G.	Royal Air Force (V.R.)	Flt.-Lieut.
Mellor, C. H.	Indian Army Ordnance Corps	Captain
Mills, C. E.	Royal Army Ordnance Corps	Sec. Lieut.
Murland, J. R. W.	Royal Inniskilling Dragoon Guards	Captain
Neave, J. W. C.	Royal Engineers	Lieutenant
Oley, F. W.	Royal Naval Volunteer Reserve	Sub-Lieut.
Olgin, C.	Royal Artillery	Gunner
Orloff, E.	Royal Engineers	Sec. Lieut.
Palk, E.	Royal Signals	Captain

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* See *Journal I.E.E.*, 85, p. 653; 86, pp. 99, 308 and 511; 87, pp. 110, 353 and 696; and 88, p. 7.

Name	*Corps, etc.*	*Rank*
Poulson, A. G. B.	Royal Artillery	Major
Pryor, C. G.	New Zealand Signals	Lieutenant
Rodman, F.	Worcestershire Regt.	Major
Schlesinger, F. W.	Royal Engineers	Major
Smith, R. H.	Royal Engineers	Major
Sully, R. B.	Royal Signals	Captain
Taylor, A. R.	Royal Air Force (V.R.)	Pilot Officer
Taylor, P. H.	Royal Air Force	Pilot Officer
Tumilty, H. G.	Royal Army Ordnance Corps	Lieutenant
van Tilburg, J. A.	South African Air Force	Lieutenant
Waters, G.	Royal Engineers	Lieutenant
Wellard, W. J. F.	Royal Air Force	Squadron Leader
Whitehead, J. W. W.	Royal Air Force	Flt.-Lieut.
Young, R. H.	Royal Engineers	Sec. Lieut.

Associates

Name	*Corps, etc.*	*Rank*
Blackburn, H. A.	Royal Army Ordnance Corps	Lieutenant
Burdick, S. G.	Royal Air Force	Pilot Officer
Churton, M. E. H.	Royal Army Ordnance Corps	Captain
Evans, P.	Royal Engineers	Lieutenant
Gordon, R. C.	Royal Naval Volunteer Reserve	Sub-Lieut.
Jackson, J. W.	Royal Air Force (V.R.)	Pilot Officer
Russell, F.	Royal Engineers	Lieut.-Col.
Stockbridge, E. R.	Royal Naval Volunteer Reserve	Lieutenant
Thomas, E.	Royal Canadian Air Force	A.C.2
Thompson, A. H.	Royal Navy	Warrant Electrician

Graduates

Name	*Corps, etc.*	*Rank*
Abbott, N. P.	Royal Naval Volunteer Reserve	Sub-Lieut.
Amos, K. J.	Royal Signals	Lieutenant
Andrew, J. C.	Royal Army Ordnance Corps	Lieutenant
Bell, R. H.	Royal Air Force	Leading Aircraftman
Bradford, W. E.	Royal Air Force	A.C.1
Branton, J. S.	Royal Signals	Sec. Lieut.
Burra, J. P. M.	Royal Navy	Lieutenant
Busby, A. W.	Royal Air Force	Corporal
Carroll, J. W.	Royal Navy	Sub-Lieut.
Carter, H. L.	Royal Engineers	Sapper
Chown, J. C. H.	Royal Naval Volunteer Reserve	Sub-Lieut.
Davies, L. H.	Royal Naval Volunteer Reserve	Sub-Lieut.
Davis, A.	Royal Air Force	A.C.2
Dewhurst, T. F.	Royal Engineers	Sapper
Dixon, W. H.	Eastern Command Headquarters	Staff Captain
Donald, L. N. B.	Indian Army Ordnance Corps	Lieutenant
Drake, P. J.	Royal Army Ordnance Corps	Private
Duncan, R. A.	Royal Naval Volunteer Reserve	Sub-Lieut.
Dunne, V. C.	Royal Naval Volunteer Reserve	Lieutenant
Dutton, J.	Royal Army Ordnance Corps	Lieutenant
Facey, J. M. C.	Royal Naval Volunteer Reserve	Sub-Lieut.
Flack, R.	Royal Army Ordnance Corps	Lieutenant
Fowler, R. J.	Royal Air Force	Leading Aircraftman
Galaway, G. R.	Royal Air Force	A.C.1
Goldsworthy, L. J.	Royal Engineers	Sec. Lieut.
Guest, R. A.	Royal Air Force	A.C.2
Hall, P. I.	Royal Air Force	Pilot Officer
Ham, T. E. G.	Royal Naval Volunteer Reserve	Lieutenant
Harrison, D. W.	Royal Naval Volunteer Reserve	Sub-Lieut.
Heal, B. J. L.	Royal Air Force (V.R.)	Pilot Officer
Hunt, H. N.	Royal Air Force (V.R.)	Pilot Officer
James, H. H.	Royal Artillery	Staff Sergt. Mechanist
Johns, R. H.	Royal Air Force	Flying Officer
Jolin, C. P.	Royal Armoured Corps	Trooper
Jordan, E. W. T.	Royal Naval Volunteer Reserve	Sub-Lieut.
Kemsley, J.	Royal Artillery	Sec. Lieut.
Kyffin, J. J. N.	Royal Naval Volunteer Reserve	Lieutenant
Kyle, W. A.	Royal Naval Volunteer Reserve	Sub-Lieut.
Lyne, R. A.	Royal Army Ordnance Corps	Private
Mackay, N. J.	Royal Army Ordnance Corps	Staff Sergt.
Maclachlan, W. S. H.	Royal Air Force	Pilot Officer
Martin, C. A. A.	Queen's Regt.	Private
Masterman, C. E.	Royal Naval Volunteer Reserve	Lieutenant
Meetens, R. G.	Royal Naval Volunteer Reserve	Sub-Lieut.
Mitchell, M.	Headquarters 2nd Corps	Captain
Neill, S. F. M.	Royal Army Ordnance Corps	Lieutenant
Newport, P. R.	Royal Army Ordnance Corps	Lieutenant
Palmer, C. W.	Royal Air Force (V.R.)	Flt.-Lieut.
Pugh, D. B.	Royal Naval Volunteer Reserve	Sub-Lieut.
Pugh, J.	Royal Artillery	Bombardier
Pulsford, H. E.	Royal Signals	Sec. Lieut.
Ridley-Martin, M. G.	Royal Signals	Captain
Scarrott, G. G.	Royal Artillery	Sec. Lieut.
Scott-Lindsley, M.	Royal Naval Volunteer Reserve	Lieutenant
Searle, A. R. I.	Royal Army Service Corps	Corporal
Shaw, A. F.	Royal Air Force (V.R.)	Flying Officer
Slocock, F. B. O.	Royal Engineers	Lieutenant
Smith, C. J.	Royal Navy	Commander
Stewart, A. W.	Royal Air Force	Pilot Officer
Tanner, R. H.	Royal Artillery	Captain
Tate, J. H.	Royal Signals	Sec. Lieut.
Thrupp, W. F.	Royal Engineers	Captain
Todd, J. K.	Royal Naval Volunteer Reserve	Lieutenant
Tricker, C. S.	Royal Engineers	Sapper
Wharton, W.	Royal Signals	Sec. Lieut.
Wickham, A. E. F.	Royal Army Ordnance Corps	Sec. Lieut.
Wiffen, C. S.	Royal Engineers	Staff Sergeant
Williams, H. M.	Royal Air Force	A.C.2
Willis, F. R.	Royal Air Force (V.R.)	Pilot Officer
Willmer, R. W.	Royal Air Force	Pilot Officer
Wood, D.	Royal Signals	Sec. Lieut.
Woodward, H.	Royal Army Ordnance Corps	Private

Students

Name	*Corps, etc.*	*Rank*
Adams, N. F.	Royal Army Ordnance Corps	Private
Akehurst, G. B.	Royal Naval Volunteer Reserve	Sub-Lieut.
Baker, G. S.	Royal Air Force	Corporal
Baker, J. W.	Royal Signals	Sec. Lieut.
Baker, S.	Royal Naval Volunteer Reserve	Lieutenant
Bartlett, P. M.	Royal Artillery	Sec. Lieut.
Black, G.	Royal Engineers	Officer Cadet

Name	*Corps, etc.*	*Rank*
Brion, E. A.	Royal Air Force	Leading Aircraftman
Coker, A. J.	Royal Engineers	Sapper
Courtis, W. J.	Auxiliary Military Pioneer Corps	Private
Cox, J. C.	Royal Canadian Air Force	Aircraftman
Cronin, M. J. J.	Royal Air Force	Corporal
Cummins, P. A.	Royal Naval Volunteer Reserve	Sub-Lieut.
Davy, N. T. J.	Officer Cadet Training Unit	Cadet
Dewhurst, D. B.	Royal Air Force	A.C.2
Douglas, G. C. G.	Officer Cader Training Unit	Cadet
Edwardes, J.	Royal Army Ordnance Corps	Lieutenant
Fairfield, I. M.	Royal Naval Volunteer Reserve	Sub-Lieut.
Fenemore, R. W.	Royal Signals	Signalman
Ferguson, H. M.	Royal Naval Volunteer Reserve	Sub-Lieut.
Fisher, H. W. W.	Royal Air Force	A.C.2
Froud, G.	Royal Army Ordnance Corps	Sec. Lieut.
Fulford, T. H.	Royal Air Force	A.C.2
Gooch, E. E.	Royal Engineers	Sapper
Grant, J. E.	Royal Signals	Signalman
Graver, L. J.	Royal Army Service Corps	Private
Gray, R. I.	Royal Air Force	Flt.-Sergt.
Griffiths, R. B.	Royal Signals	Signalman
Hancock, L.	Officer Cadet Training Unit	Cadet
Harris, R. A.	Royal Air Force	A.C.1
Harvey, R. A.	Royal Air Force	A.C.2
Heard, J. B.	Royal Air Force (V.R.)	Flying Officer
Heidenstam, F. H. S.	Royal Army Ordnance Corps	Sergeant
Henson, C. S.	Royal Air Force (V.R.)	Pilot Officer
Herbert, A. E.	Royal Signals	Signalman
Hill, R. E.	Royal Artillery	Lance-Bombardier
Hood, E. H.	Royal Army Service Corps	Private
Hunt, T. P.	Royal Naval Volunteer Reserve	Sub-Lieut.
Ingram, T. P.	Road Traffic Control Group	Sergeant
Jackson, H.	Royal Air Force	A.C.2
Jarvis, J. T. K.	Royal Signals	Corporal
Judge, J. A.	Royal Engineers	Lance-Corporal
Kerr, G. H.	Royal Army Ordnance Corps	Private
Kerrich-Walker, H. V.	Royal Artillery	Sec. Lieut.
Kirtley, P. A.	Royal Naval Volunteer Reserve	Sub-Lieut.
Langford, R.	Royal Naval Volunteer Reserve	Sub-Lieut.
Leng, I. J.	Royal Naval Volunteer Reserve	Sub-Lieut.
Letchford, A. W.	Royal Naval Volunteer Reserve	Sub-Lieut.
Lever, H.	Royal Air Force	Aircraftman
Little, J.	Royal Air Force	Leading Aircraftman
McCall, R. A.	Royal Naval Volunteer Reserve	Sub-Lieut.
Macdonald, E. R. L.	Royal Naval Volunteer Reserve	Sub-Lieut.
Marlow, J.	Royal Army Service Corps	Artificer
Marriott, F. G.	Royal Signals	Signalman
Mason, N. A. K.	Royal Signals	Sec. Lieut.
May, D.	Royal Air Force	A.C.2
Maynard, R. G. W.	R.N.V.R. (Fleet Air Arm)	Naval Airman 2
Meyler, T. D.	Royal Engineers	Sapper
Moir, K.	Royal Australian Navy	Electrical Artificer
Monk, R.	Royal Air Force	A.C.2
Morgan, C. H.	Royal Armoured Corps	Trooper
Naylor, F. D.	Royal Naval Volunteer Reserve	Sub-Lieut.
Newton, H. E.	Royal Artillery	Gunner
Ord, C. B.	Royal Naval Volunteer Reserve	Sub-Lieut.
Owen, H. P. H.	Royal Air Force	A.C.2
Palmer, T.	Royal Army Ordnance Corps	Staff Sergeant
Pickthall, A. H.	R.N.V.R. (Fleet Air Arm)	Naval Airman 2
Porter, J. W.	Royal Signals	Captain
Probert, H. J.	Royal Engineers	Sapper
Prout, D. C.	Royal Naval Volunteer Reserve	Sub-Lieut.
Prout, R. W.	Royal New Zealand Air Force	Sergeant
Pyman, L. L.	Royal Air Force	Pilot Officer
Reynolds, R. A.	Royal Air Force	A.C.2
Ross, K. W.	Royal Air Force	A.C.2
Ross, V. J.	Royal Navy	Sub-Lieut.
Rothwell, H. K.	Royal Signals	Signalman
Savage, J. R.	Royal Signals	Signalman
Scampton, T. R.	Royal Naval Volunteer Reserve	Sub-Lieut.
Smith, R. E.	Royal Air Force	Pilot Officer
Smith, T. C.	Royal Air Force	A.C.2
Stefani, I. L.	Royal Engineers	Sapper
Stevenson, H. C.	Royal Engineers	Captain
Stuchbury, K. J. H.	Officer Cadet Training Unit	Cadet
Suckling, M. P.	Royal Navy	Electrical Artificer
Sutherland, A. T.	Royal Naval Volunteer Reserve	Sub-Lieut.
Sutton, A. J.	Royal Navy	Ordinary Seaman
Tait, W. L.	Royal Air Force	Corporal
Tipler, L. S.	Royal Air Force	A.C.2
Trayler, P. A.	Royal Naval Volunteer Reserve	Sub-Lieut.
Tricker, G. R.	Royal Signals	Signalman
Walker, F.	Royal Naval Volunteer Reserve	Sub-Lieut.
Walker, S. H.	Royal Signals	Signalman
Warburton, P.	Royal Air Force	A.C.2
Ward, N. C.	Royal Army Ordnance Corps	Private
White, G. C. E.	Royal Signals	Signalman
Willis, H. R.	Royal Air Force	Sergeant
Winter, J. L.	Indian Army Ordnance Corps	Lieutenant
Winter, R. M.	Royal Air Force	A.C.2
Withington, W. B.	Royal Navy	Electrical Artificer
Wood, G. H.	Royal Air Force	A.C.2
Woodford, E. V.	Royal Air Force	A.C.1
Woolley, D. H.	Royal Engineers	Sapper
Worsnop, W.	Royal Air Force	A.C.2
Wye, W. G. H.	Royal Air Force	A.C.2

PROMOTIONS AND TRANSFERS OF MEMBERS ON SERVICE WITH H.M. FORCES

(SIXTH LIST)*

Members

Name	*Corps, etc.*	*Rank*
Baker, J. H. E.	Royal Signals	Major
Ewer, G. G.	South African Staff Corps	Colonel
Hogg, D. B.	Royal Artillery	Captain
Palmer, W. T.	Royal Signals	Captain

* See *Journal I.E.E.*, 86, pp. 311 and 510; 87, pp. 112 and 356; and 88, Pt. I, p. 6.

Associate Members

Name	*Corps, etc.*	*Rank*
Allen, M.	Officer Cadet Training Unit	Cadet
Andrewes, H.	Royal Air Force (V.R.)	Squadron Leader
Armitage, J. G.	Royal Naval Volunteer Reserve	Lieutenant
Bates, H. O.	Royal Army Ordnance Corps	Captain
Bird, W. A.	Royal Army Ordnance Corps	Lieutenant
Carr, A. S.	Royal Air Force (V.R.)	Flying Officer
Collingbourne, H. L.	Royal Air Force	Pilot Officer
Corson, G. J.	Royal Army Service Corps	Captain
Draeger, K. G.	Royal Naval Volunteer Reserve	Lieutenant
Drummond, B. G.	Royal Artillery	Major
Furnell, P. G.	Royal Naval Volunteer Reserve	Lieutenant
Gill, W. E.	Royal Signals	Major
Glanister, C. W.	Royal Engineers	Major
Horgan, M. O.	Royal Engineers	Major
Huff, W. C.	Royal Signals	Lieut.-Col.
Jacobs, P. G.	Royal Signals	Captain
Johnson, G. W.	Royal Army Ordnance Corps	Captain
Lewis, H. A.	Royal Army Ordnance Corps	Major
Meldrum, J. P. A.	Royal Signals	Major
Nield, H. B.	Royal Engineers	Captain
Page, A. R.	Royal Engineers	Lieutenant
Parnall, E. J.	Royal Artillery	Lieut.-Col.
Reeves, R. W. C.	Royal Signals	Major
Stead, C.	Royal Signals	Captain
Thompson, D. H. H.	Royal Navy	Commander
Thompson, D. R. W.	Royal Air Force	Group Captain
Vinten-Fenton, C. V.	Royal Engineers	Lieutenant
Warhurst, F.	Royal Signals	Captain
Wood, P. T.	Royal Engineers	Major

Associates

Name	*Corps, etc.*	*Rank*
Newland, E. W. J.	Royal Engineers	Lieutenant
Wellingham, H. J.	Royal Artillery	Major

Graduates

Name	*Corps, etc.*	*Rank*
Allison, S. S. H.	Royal Artillery	Sergeant
Ashworth, H.	Royal Naval Volunteer Reserve	Lieutenant
Bambery, C. M.	Royal Naval Volunteer Reserve	Lieutenant
Beatson, C. J.	Royal Army Ordnance Corps	Lieutenant
Beattie, M. H.	Royal Signals	Captain
Beazley, B. S.	Royal Engineers	Lieutenant
Bennett, W. G.	Royal Engineers	Captain
Bishop, T. R. J.	Royal Engineers	Major
Black, P.	Royal Army Ordnance Corps	Lieutenant
Brown, H. J.	Royal Naval Volunteer Reserve	Lieutenant
Calver, W. H.	Royal Army Ordnance Corps	Sec. Lieut.
Connerton, C. D.	Royal Air Force	Squadron Leader
Dykes, J. O.	Royal Air Force	Flt.-Lieut.
Fisher, A. J. M.	Royal Artillery	Captain
Goering, P. H.	Royal Army Ordnance Corps	Captain
Gooud, W. R.	Royal Naval Volunteer Reserve	Lieutenant
Greening, C. E.	Royal Army Ordnance Corps	Lieutenant
Harding, G. R.	Royal Artillery	Captain
Headland, R. C. C.	Royal Engineers	Sergeant
Jackson, A. E.	Royal Engineers	Sec. Lieut.
Kassell, E. D.	Royal Engineers	Major
Leonard, C. A. W.	Royal Army Service Corps	Corporal
Linsell, R. F.	Royal Naval Volunteer Reserve	Lieutenant
Locke, C. F.	Royal Naval Volunteer Reserve	Lieutenant
Marriott, T. W.	Auxiliary Military Pioneer Corps	Corporal
Marshall, D.	Royal Engineers	Lieutenant
Marshall, R. V.	Royal Army Service Corps	Lance-Corporal
Mather, W. H.	Royal Artillery	Lieut.-Col.
Morgan, H. D.	Royal Artillery	Captain
Morgan, J. T.	Royal Signals	Sec. Lieut.
Morgan, P. A.	Royal Army Ordnance Corps	Captain
Nicholson, J.	Royal Engineers	Sec. Lieut.
Oswald, J. W.	Royal Naval Volunteer Reserve	Lieutenant
Pannell, J. W.	Royal Naval Volunteer Reserve	Lieutenant
Partridge, G. H.	Royal Signals	Lieutenant
Penfold, T. B. D.	Royal Naval Volunteer Reserve	Lieutenant
Pickard, H.	Royal Signals	Major
Reed, A.	Royal Artillery	Sec. Lieut.
Rhodes, J. B.	Royal Artillery	Gunner
Ryan, H. N.	Royal Army Service Corps	Captain
Salt, T. C. F.	Royal Army Ordnance Corps	Captain
Small, W. H.	Officer Cadet Training Unit	Cadet
Smith, E.	Royal Naval Volunteer Reserve	Lieutenant
Sneath, W. S. G.	Royal Engineers	Sec. Lieut.
Thompson, J. J.	Royal Naval Volunteer Reserve	Lieutenant
Varley, L. J.	Royal Signals	CompanyQuartermaster Sergt.
Wakefield, J. A.	Royal Engineers	Sec. Lieut.
Warne, G. H.	Royal Naval Volunteer Reserve	Lieutenant
Webster, E. A.	Royal Signals	Sec. Lieut.
Wilson, N. J.	Royal Naval Volunteer Reserve	Lieutenant

Students

Name	*Corps, etc.*	*Rank*
Anderson, R.	Officer Cadet Training Unit	Cadet
Bainbridge, T. R.	Royal Air Force	Corporal
Barr-Wells, D. R.	Royal Artillery	Sec. Lieut.
Bishop, R. G.	Royal Engineers	Sergeant
Clarke, N. M.	Royal Air Force	Leading Aircraftman
Coggins, W. A.	Royal Army Ordnance Corps	Corporal
Collinson, W. F. P.	Royal Army Ordnance Corps	Staff Sergeant
Coventry, J. H.	Royal Engineers	Lance-Corporal
Donnelly, H. E. A.	Royal Engineers	Sec. Lieut.
Johnson, D. W.	Royal Engineers	Sec. Lieut.
Knights, H. R.	Royal Naval Volunteer Reserve	Lieutenant
Long, H. J.	Royal Naval Volunteer Reserve	Lieutenant
Morris, A. R.	Royal Air Force	A.C.1
Ord, J. A.	Royal Signals	Sec. Lieut.
Outhwaite, R.	Royal Artillery	Sergeant
Poyser, R. W. R.	Royal Artillery	Bombardier
Rake, C. E. T.	Royal Engineers	Corporal
Robinson, R. E. H.	Royal Signals	Major
Starnes, H. W.	Royal Army Ordnance Corps	Sergeant

Name	*Corps, etc.*	*Rank*
Tucker, E.	Officer Cadet Training Unit	Cadet
Wade, W. R.	Royal Signals	Sec. Lieut.
Westgate, R. G.	Royal Naval Volunteer Reserve	Lieutenant

ELECTIONS AND TRANSFERS

At the Ordinary Meeting of The Institution held on the 20th February, 1941, the following elections and transfers were effected:—

Elections

Associate Members

Dobson, Cecil George.
Duncan, Albert.
Longfield, John Foster, Major, R. Signals.
Middleton, Robert Wood.
Rodman, Frank, Major, Worcestershire Regt.
Toczylowski, Henry.
Whitehead, John William W., Flight-Lieut., R.A.F., B.Sc.

Associates

Beabey, Percival Leonard.
Honey, Leonard William.
Peedle, John Bagnall.
Russell, Fred, Lieut.-Colonel, R.E.

Graduates

Akers, Bernard Horace.
Barton, Harry Herbert.
Bigg, Edward James.
Bouvet, Charles Andre A.
Butler, William.
Cartwright, Harry, B.A.
Daglish, Peter John, B.Sc.
Eastwood, Norman.
Edgar, Anthony Kennedy, B.Sc.
Fenwick, John.
Glover, Jack Kenneth.
Greenburg, Theodore Herzl, B.A.
Jackson, Bertram Carlisle.
Jones, John.
Leaver, Harold.
Menzies, Andrew.
Mercer, John.
Moody, John Edward.
Morrison, Samuel James, B.Sc.
Sewell, Ivan Robert.

Students

Anderson, John.
Bass, Alfred William.
Bell, Colin.
Blacklock, George.
Brosan, George Stephen.
Camack, David Edward.
Cannell, Robert Leslie.
Clark, Richard Gilbert.
Coltart, Christopher Roland.
Corbett, Harry.
Crawford, John.
Crossland, Walter.
De Kretser, John Henry G.
Dodridge, Denis Edwin.
Dodson, Jack.
Ellison, Arthur James.
Finlay, John Chadwick.
Fletcher, Ralph Frederick.
Freeland, Maurice Montague.
Garlick, Norman Laurence.
Geddes, William Geoffrey.
Gill, Basil Frederick.
Hadaway, William Douglas.
Hagger, David Ashley.
Hancock, Leslie.
Hardwick, Edgar.
Hearsum, Desmond Roy.
Helliwell, Stephen.
Hemsell, Geoffrey Maxfield.
Hewitt, Ronald Gwyn.
Holyoake, Cedric Jennings.
Howard, Peter Reuben.
Hudson, Jack.
James, Ronald.
Jones, Claude Eric C.
Kelly, John Arnold.
Kitchenn, Ronald Graley.
Ledger, Robert.
Liller, Kenneth Wolstenholme.
Ludlow, Edward Geoffrey.
McDougall, Andrew Dempster.
Mackertich, Raymond George.
McLachlan, Kenneth Roy.
Meatyard, Leslie Richard.
Munro, Douglas.
Newman, Bernard Eric.
Nunn, Richard Geoffrey.
Pearce, Ronald Frederick.
Peck, Charles Edward.
Pender, Norman William.
Pennell, Peter.
Pharaoh, Kenneth Charles A.
Pickard, Robert Jackson.
Poole, Robert Thomas.
Post, Ronald James.

Students—continued.

Preece, James.
Price, Edgar William.
Reeve, Leslie Arthur.
Richmond, David.
Rumbellow, Victor George.
Russell, Matthew Aird.
Sergison, Philip Francis.
Sharratt, Fred.
Speller, Kenneth William.
Speight, Jack.
Stevenson, Peter Francis.
Stokes, Maurice Raymond.
Tiwary, Suresh Chandra, B.Sc.
Turner, Gordon William L.
Wain, Leslie.
Watson, Norman George.
Watts, Francis Julian R.
White, Arthur Sidney.
Woolley, Arthur Eric.

Transfers

Associate Member to Member

Ashdowne, Herbert Arthur, B.Sc.
Guilfoyle, Thomas James.
Naylor, Felix Samuel, B.Sc. (Eng.).

Associate to Associate Member

Cartlidge, Robert.
Galloway, James.

Graduate to Associate Member

Bibby, Herbert Frederick, B.Sc.Tech.
Blake, Kenneth William.
Clark, Robert.
Coomber, Robert Edward.
Davidson, George Hunter.
Foulkes, Christopher Henry.
Gerry, Cyril Harry.
Hogg, Francis Granville, B.E.
Jones, Edward, B.Sc.(Eng.).
Rochester, Robert.
Smith, Humphrey Montague, B.Sc.
Smith, Ralph Balmforth, Ph.D., B.Sc.
Tatham, Francis Everard, B.Sc.(Eng.).

Student to Associate Member

Brown, James Kinghorn, B.Sc.

Student to Associate

Jepson, Albert Edward.

The following transfers were also effected by the Council at their meeting held on the 20th February, 1941:—

Student to Graduate

Anderson, Charles Neil.
Betts, Edgar Newman.
Brettell, Bernard John.
Broadbent, Albert.
Brooks, Robert Hedley.
Burgess, David Alexander, B.Sc.(Eng.).
Buss, Donald Arthur.
Butler, William Martin.
Davie, Owen Hosmar.
Dodd, Thomas Frederick.
Fox, Donald Ernest, B.Sc.
Gordon, Norman.
Halliday, Jack Hubert.
Hampson, Henry Gordon.
Harris, James.
Harrison, John Michael.
Haynes, Eric Ralph, Sec. Lieut., B.Sc.(Eng.).
Hood, Norman Lovell.
Hunt, Henry Norman, Pilot Officer, R.A.F.
Hurst, William.
Imber, Richard Charles.
Lang, George Andrew.
Lawrence, James Scott.
Lowe, Alexander James M., B.Sc.(Eng.).
Major, William.
Munns, John George W., B.Sc.
Nawab, Syed Hasan.
Newsome, Arthur.
Ord, Ian.
Peet, Richard Henry.
Prabhakaran Nayar, Chandrasekharan Rajarajavarma.
Quinn, Joseph Francis.
Saunders, Joseph Brown.
Saxby, Francis Hugh.
Shepherd, George Ronald.
Shore, Alec.
Simmons, Jack.
Smith, Harvey Jefferson.
Smith, John.
Spencer, Percy Vernon.
Taylor, Arthur Joseph W.
Thompson, William Alexander.
Vexler, Nataniel.
Whitehorne, Alan George.
Widdowson, Albert.
Williamson, Drummond.
Winnard, James Guy.
Worthington, Thomas Scott.

ARGENTINE CENTRE: CHAIRMAN'S ADDRESS

By M. F. RYAN, C.B.E., Member.*

"JOB ANALYSIS"

(ABSTRACT *of Address delivered at* BUENOS AIRES, 17*th May*, 1940.)

Before accepting nomination as your Chairman, I endeavoured to make it plain that I should not be able to make any technical contribution to your discussions. For this reason I have selected for my Address a subject of general interest which I trust will contain some information that may be profitably used in any kind of undertaking, electrical or otherwise.

Definition

"Job Analysis" is the term used by the London, Midland and Scottish Railway to apply in general to organized departmental and inter-departmental analyses. It means the analysis of each individual item of work; its relation to other items; and the analysis of the work of particular individuals in order to discover whether particular operations (*a*) are necessary in whole or in part; (*b*) can be amalgamated or co-ordinated with any other activity; and (*c*) are being carried out in the most efficient and economical way.

It should be carefully noted that one of the principal objects of this process is to eliminate useless work and to suppress duplication. It also aims at the selection and distribution of staff and appliances or workmen and machinery, to give the maximum effect at the minimum cost. It does not seek to exploit any man beyond his normal capacity. These conditions are the essence of management. Job analysis is one of the means to realize them.

History

Job analysis is no novelty. It embraces a process which has been in force for generations in factories and workshops. I refer to the analysis of methods involved in the fixing of piece-work rates. The adaptation of job analysis, however, to clerical work in offices and stations and to the operation of shunting yards, stations and running sheds, has not been so widely known. It is in these spheres that the best results have been obtained from job analysis on the Pacific Railway.

Procedure

The methods used by each analyst are identical as far as the approach is concerned. Every employee subject to analysis has to give a written detail of all his activities, how the work is performed and why. It is remarkable how, by this means, the analyst is able to appreciate, in a general sense, where the weak spots lie, even before the investigation is commenced. The man who is conscious of having a full-time job limits himself to a brief detail of each of his duties, but the man who knows that he cannot pass the test almost invariably gives a long description of his activities, frequently adding a footnote to the effect that he affords considerable assistance to one or another during the month. These statements are carefully studied, and the work of one is compared with that of another, so that when the actual inquiry is initiated the analyst is well prepared for the explanations given verbally by the employees themselves. Moreover, sometimes the work is of such a nature that the analyst can assess its time value even before the interview, so that, when the particular job comes up for discussion, the suggestion from the analyst that it should not take longer than a certain time generally disarms the employee, who immediately acquiesces or manifests indignation. Either result is equally satisfactory—it is but a means of getting at the truth.

Job analysis may not always result in staff reductions. There are circumstances in which it reveals understaffing. It is important that under these conditions the additional help required shall be immediately forthcoming if the abuse of keeping staff "up one's sleeve" is to be checked.

A similar cause of waste which may be described as "keeping staff to meet peak periods that recur at regular intervals" is more difficult to overcome. A situation of this kind was presented when job analysis was first instituted in a group of eight district offices of the railway. The result was a net reduction of 24 in the number of employees of the railway as a whole.

Job analysis has also been instrumental in reducing by 40 the number of employees in the accounting department.

It is fair comment to state that many of the improvements might have been effected without the intervention of job analysis. The answer is that with its aid they can be carried out with absolute certainty of success and can be made more far-reaching in their effect.

Further examples of staff economy by the use of job analysis are a reduction of 35 in the personnel of the headquarters clerical staff, of 90 in the divisional offices, and of 20 in three of the principal stations.

Useless Records

The economies effected by job analysis have not all been brought about by the elimination of waste of time: quite a considerable saving has resulted from the suppression of useless records.

Under this heading are represented those records which can be discarded owing to the information having been duplicated, and which can be replaced by an extra column added to one of the records; and also the type of record which at some remote time was found to be useful and which has been kept up to date in case it may be wanted.

Further types of records which arouse suspicion are the visible or card indexes. No wholesale condemnation is involved, but there are those who have a weakness for these equipments, and cases have arisen of men spending many hours each month tabulating information in a neat hand, or writing up the cards with a typewriter, thereby accumulating a mass of detail which may never be required.

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* Ferrocarril de Buenos Aires al Pacifico.

Redundant Staff

The effect of job analysis on the Pacific Railway has been to reduce the annual wage bill by hundreds of thousands of pesos. The process still continues. Now to achieve this result it seems logical that either the wages of the staff have been reduced or employees have been discharged, but I am pleased to say that no man's wage has been cut and that no permanent employee has been laid off.

Let me explain that the circumstances are of a special nature. In order to minimize unemployment, in the year 1931 the President of the Republic ordained that the scales of pay of railwaymen were not to be reduced and that surplus staff was to be retained in service. The cost of this measure was met by an arrangement whereby all officers and men were laid off without pay for a short period every week. Except in workshops this arrangement was subsequently changed to a temporary percentage all-round cut in wages. Since the date in question practically no fresh employees have been engaged and the wage economy referred to has been realized through the staff retiring on pension or leaving the service for any other reason and not being replaced.

When the work of a dependency, be it office or station, is reformed in the light of the job analyst's recommendation, it is essential that the redundant staff should be removed. If this is not done, reforms are deferred until fresh posts are found for the surplus men. This delays progress, because as soon as the men have settled down to the new conditions it has usually been found that a second revision produces still further reduction of work.

It has to be emphasized that the inauguration and progress of job analysis and other recommended arrangements should not be delayed because any consequential staff rearrangements cannot immediately be carried into effect. A job analysis may show the proper complement for a given office: if it cannot be implemented because there are no means of disposing of the surplus staff, nevertheless a standard will have been laid down for attainment as quickly as possible. The creation of a pool for surplus men provides the solution. Another item which has been found to delay progress has been the postponement of an improvement in order that a large stock of existing forms may be used up before new ones are introduced.

Job Analysts

It has been found that two important characteristics to be taken into account in selecting job analysts are tact and thoroughness. On their tact will depend the propagation of the idea of analysis. Because job analysis is a question of the proper sifting of minute details, thoroughness is essential.

The success or non-success of an investigation is largely dependent on the ability of the analyst to dominate the situation. He must remember that he commences his work with a severe handicap, namely that every man he has to observe is deeply suspicious of his motives. He has to endeavour not to antagonize the staff by introducing wrong methods of approach; he must at times be a sympathetic listener, also a man of character and not swayed by any ulterior motives.

Care should be taken to obtain the confidence of the chief of the dependency under analysis, as the success of any reorganization that may be necessary will depend to a great extent on the measure of co-operation received from this employee. If the introduction of improved methods is considered necessary the matter should be discussed with him, treating him as a colleague as far as the analysis of his own office is concerned.

The job analyst should not, however, allow the opinion of any employee to deter him from thoroughly sifting every function performed in the office. His report should be based on his own findings and not on second-hand information.

Scope

If it is suggested or even hinted to the head of a business that unnecessary waste is taking place in his organization he is certain to resent it. To carry conviction a few initial cases have to be proved out within an organization. Once the chiefs have appreciated that job analysis is an arm that assists them to secure improved results and not to criticize their work they adopt it and make it work.

I am convinced that even the smallest undertaking would be the better for job analysis.

Conclusion

To sum up, job analysis is merely the systematic revision of an organization or a section thereof. As an isolated investigation it is merely an irritant of academic interest. Used as an instrument in a scheme of reform it is of immense value. It is best applied in successive stages, like a series of riddles with a diminishing size of mesh.

To secure results it cannot be applied half-heartedly. It must have the whole-hearted support of those directing the organization. Furthermore, some alternative occupation must be provided for the staff that are riddled out.

THE EXTRACTION OF ELECTRONS FROM COLD METALS AT HIGH FIELD-STRENGTHS*

By PROFESSOR WILLIS JACKSON, D.Sc., D.Phil., Associate Member,†
and A. E. CHESTER, M.Sc., Graduate.‡

(*Paper received* 25th *April*, 1940.)

SUMMARY

The paper is a résumé of the considerable amount of published work on the extraction of electrons from cold metals in high vacua by the application of high field-strengths. A sufficient description of the experimental technique is given to bring out the difficulties met with in attempts to correlate theory and practice. It is concluded that the Fowler–Nordheim theory is substantially correct in giving the dependence of field currents on the field strength and temperature, and also in respect of the energy distribution of the electrons involved. The extension of this relation to include the effect of electropositive surface films appears to be justified experimentally, though there is need of further quantitative confirmation. The significance of field emission in relation to breakdown phenomena, the mercury arc and materials of non-linear electrical characteristics is discussed. The authors trust that the list of references given is a complete one.

(1) INTRODUCTION

It is well known that when the temperature of metallic surfaces is raised sufficiently, or when such surfaces are suitably irradiated at room temperature, they become capable of emitting a copious supply of electrons. The utilization of these phenomena of "thermionic" and "photo-electric" emission in the thermionic valve and photo-electric cell respectively has made possible very far-reaching developments in electrical engineering during recent years. It is also common knowledge that when a cold metal surface is bombarded with charged particles, either electrons or ions, of adequate energy, there results an emission of what are called "secondary" electrons, and that this effect is utilized to advantage in the screen-grid valve, in electron multipliers, and in cold-cathode gas-discharge devices. It is not so well known, however, that electrons may also be extracted from metallic surfaces at room and lower temperatures purely by the application at the surface of sufficiently high field-strengths. This phenomenon of "field," "cold-cathode" or "auto-electronic" emission is observed in the highest vacua, and while it may also occur in cold-cathode gas-filled devices it is not to be confused with such secondary effects as occur in the latter once the discharge has been initiated. Although, as we shall see, there is no question of a critical field-strength for the initiation of field emission, its magnitude is not normally sufficient for measurement to be possible at field strengths below 10^5–10^6 volts per cm.

Little deliberate use is as yet being made of the phenomenon of field emission outside the sphere of the cold-cathode X-ray tube. On the other hand, it is probably field emission which initiates the discharge between opening switch contacts, while the phenomenon is apparently fundamental to the action of the mercury arc[12, 41] and of certain materials of non-linear characteristics.[52] These, combined with the difficulties to which it may give rise in the construction of high-voltage high-vacuum equipment,[62] can be said to have raised the phenomenon to the sphere of engineering importance. Quite apart, therefore, from its fundamental physical interest, a presentation of the existing knowledge on the subject appears to be justifiable and desirable.

An important point should be borne in mind throughout the discussion to follow. In field-emission experiments small fluorescent spots are often observed on the anode, and the position and degree of illumination of these spots may be observed to change without external interference. This reveals that the field currents are not emitted uniformly over the surface of the cathode, but consist chiefly of pencils of electrons emerging from a few minute areas. These active areas consist in general of small surface protrusions at which the applied field-strength is much greater than the average value over the surface as a whole. The impossibility of determining the dimensions of these protrusions directly and therefore of calculating the effective field-strength and current density in given cases has complicated the attempt to correlate theory and experiment, and retarded progress towards an understanding of the phenomenon.

(2) EXPERIMENTAL TECHNIQUE

In investigating the phenomenon of field emission some workers have chosen to work on wires of circular section and others on sharp metallic points. Apart from this, no substantial difference exists between the techniques adopted by the various experimenters, and it will be sufficient to describe that employed by Millikan and Eyring.[14]

In Fig. 1 the tungsten wire under test (diameter 0·00123 cm.) is shown mounted along the axis of a copper tube anode C, 1·625 cm. diameter, supported inside the glass enclosure A. The ends of this cathode wire were connected to the negative side of the 12 000-volt d.c. generator D, with provision for sending a heating current through the wire from the battery B_1. The wire was kept taut by means of the 4-gramme weight I, but in order to prevent breakage when the wire was operated at temperatures above 1 000° K. provision was made for reducing this load by energizing the electromagnet E. The anode C was supported on a thick tungsten wire sealed into the glass container at P, and the glass supporting-post was provided with an earthed guard ring, and with a sleeve to prevent the seal from becoming covered with a copper deposit during the degassing process. The lead through P was taken to a tilted electroscope, or shunted galvanometer, for current measurement and was surrounded by a glass tube covered with tinfoil and earthed. An electric heater, wound on an earthed metal cylinder, surrounded the glass enclosure.

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* Written communications are invited, for consideration with a view to publication, on papers published in the *Journal* without being read at a meeting. Communications (except those from abroad) should reach the Secretary of The Institution not later than one month after publication of the paper to which they relate.

† University of Manchester.

‡ University of Manchester. (The research described in this paper was carried out during Mr. Chester's tenure of the Ferranti Scholarship.)

It had long been known that the history of the cathode surface exercised a very great effect on the field strength necessary to extract electrons. In confirmation of this, Millikan and Eyring observed that a fresh surface often gave a large emission which varied with time, so that the results were not at first reproducible. If the surface was "conditioned" by drawing large currents from it, the emission usually became reproducible at field strengths lower than that applied for this conditioning purpose. A set of their results illustrating this effect is shown in Fig. 2. Furthermore, heating the filament to a high temperature, 2 300° K. or over, was found to change the wire surface in such a way as to increase considerably the field required to draw a given current from it at room temperature.

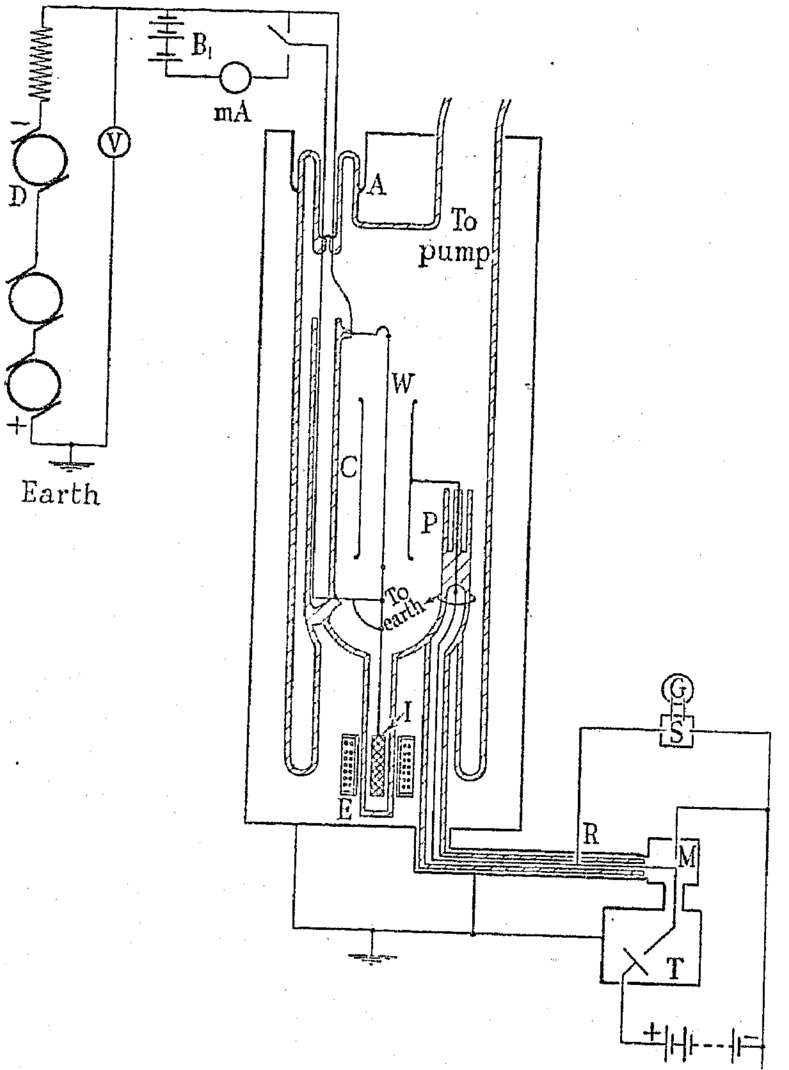
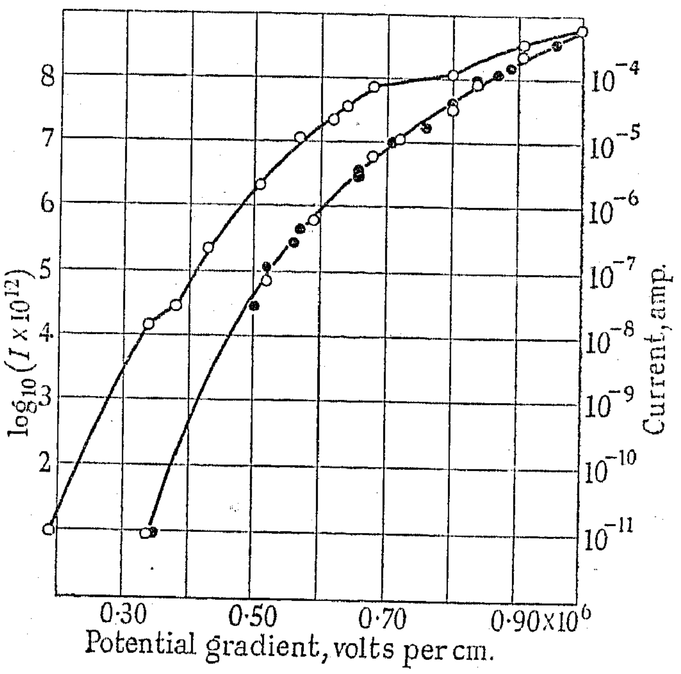


Fig. 1.—Diagram of circuit arrangements employed by Millikan and Eyring.

Arising out of these and similar observations, the conditioning procedure which may now be regarded as necessary for the establishment of a satisfactory degree of vacuum and of reliable experimental conditions generally, is as follows: The containing glass vessel must be baked under vacuum at 400°–500° C. for several hours; the anode must be raised to a red heat by electron bombardment or induction heating, and this temperature maintained for a period up to 1 hour, and the cathode wire heated to 2 300°–2 700° K. for an hour or more. The degree of vacuum attained by Millikan and Eyring, using high-speed mercury pumps, was less than 10^{-6} mm. Hg. Other experimenters have operated at 10^{-8} mm.

In the electrode assembly of Fig. 1, the electron supply for anode bombardment was provided by a zigzag filament situated about 0·5 cm. from the outside of the anode cylinder.

On the assumption that the wire surface is perfectly smooth, the field strength at this surface is readily calculated. For the wire of 0·00123 cm. diameter used by Millikan, this field strength E_m was given by $228V$, where V is the potential difference between the wire and its concentric anode C. As mentioned previously, this is not the field-strength value on which theoretical correlation can be based directly. The actual field-strength at the surface is determined in part only by the large-scale geometry of the electrode assembly: it is governed also by the micro-geometry of such irregularities as exist on the cathode surface. At these irregularities the effective field-strength will be greater than the above-mentioned value E_m by a factor, β say, which may be considerably in excess of unity depending on the shape of the protrusions.



○ Increasing gradient. ● Decreasing gradient.

Fig. 2.—Results obtained by Millikan and Eyring.

Schottky[11] has estimated that for a half-cylinder on an infinite plane, $\beta = 2$; for a second cylinder on this cylinder and of half its radius, $\beta = 2^2$; and so on. For a hemispherical boss on an infinite plane Stern, Gossling and Fowler[29] and Compton and Langmuir[32] give $\beta = 3$ as the calculated value. In practice, where adequate care is not taken in preparing the metal surface, it appears that this factor may reach values as high as 100 or more.

The effect of conditioning the cathode wire, either by drawing large field currents from it or by heating it to a high temperature, may be envisaged as a process of smoothing out at least the more prominent surface irregularities. There will no doubt be a further action, however, namely that of removing particles of electropositive impurities—

sodium, potassium and the like—which are invariably associated with fresh metal surfaces, and which facilitate electronic emission (see Section 4).

(3) THE BEHAVIOUR OF PURE METALS, AND THE FOWLER-NORDHEIM THEORY OF FIELD EMISSION

Although some measurements have been made on platinum and nickel,[19] molybdenum,[37] copper,[35, 42] mercury[38, 43, 53] and steel,[19, 35, 48] attention has been concentrated mainly on tungsten, tested usually in wire form but in some instances as points. For the present, reference will be made only to the experimental results on the latter material, firstly in respect of the variation of field emission with field strength at constant temperature, and secondly regarding the dependence of this emission on temperature at constant field-strength.

In preface, it is worth while to mention that up to 1926, by which date a good deal of experimental evidence had accumulated, attempts to explain the phenomenon of cold-cathode (field) emission had centred round the possible applicability of Schottky's theory of the field effect on thermionic emission.[6] This theory explains very satisfactorily the observation that the thermionic current emitted by a heated wire is dependent not only on the wire temperature but also on the magnitude of the field strength which may be applied at the wire surface. Thus, whereas the current density of thermionic emission at zero field is given by the well-known formula

$$i = AT^2\epsilon^{-b/T} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where T is the absolute temperature and A and b are constants, according to Schottky the current density at field strength E is modified in accordance with the law

$$i = (AT^2\epsilon^{-b/T})\epsilon^{\frac{e^{3/2}}{kT}\cdot E^{\frac{1}{2}}} \quad . \quad . \quad . \quad . \quad (2)$$

in which e is the electronic charge and k Boltzmann's constant. The essential correctness of this relation in the thermionic region has been verified by de Bruyne[22] and by Pforte[20] up to field strengths of the order of 10^6 volts per cm. It is seen that the predicted rise of current with field strength is of the form $\epsilon^{E^{\frac{1}{2}}/T}$; the fact, now abundantly checked, that the field emission at normal (room) temperatures does not vary with field strength and temperature in this manner, disposes of the possible applicability of this theory to the subject under discussion.

(3.1) Experimental Dependence on Field Strength

The dependence of field emission on the gradient at the cathode surface was first formulated by Millikan and Lauritsen[17] in 1928 on the basis of experimental results published 2 years previously by Millikan and Eyring,[14] and by Gossling,[15] in the empirical relation

$$I = A'\epsilon^{-b'/E_m} \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Here A' and b' are constants and E_m is the field strength calculated from the large-scale geometry of the electrode system. Their justification for this relation is shown in Fig. 3, the results in which relate to measurements on a well-conditioned tungsten surface; its form has been confirmed by many later workers, in the case of Abbott and Henderson[44] down to currents as low as 10^{-17} amp. A more complete relation, however, is probably

$$I = A''E_m^2\epsilon^{-b''/E_m} \quad . \quad . \quad . \quad . \quad (4)$$

from which, for the significant order of field strengths, (3) is practically indistinguishable. The inclusion of E_m^2 as a factor was suggested originally by the similarity between equations (3) and (1).

In view of the wide range of current and field strength (E_m) over which relation (3) has been found applicable, there would seem to be no justification for the early conception of a certain critical field-strength for the initiation of field emission, though in only one case does it appear to have become significant for field strengths below 10^5 volts per cm.[62] In this case the area of the emitting surfaces was extremely large, and the total applied voltage also large, compared with those which have been used in formal studies of the phenomenon.

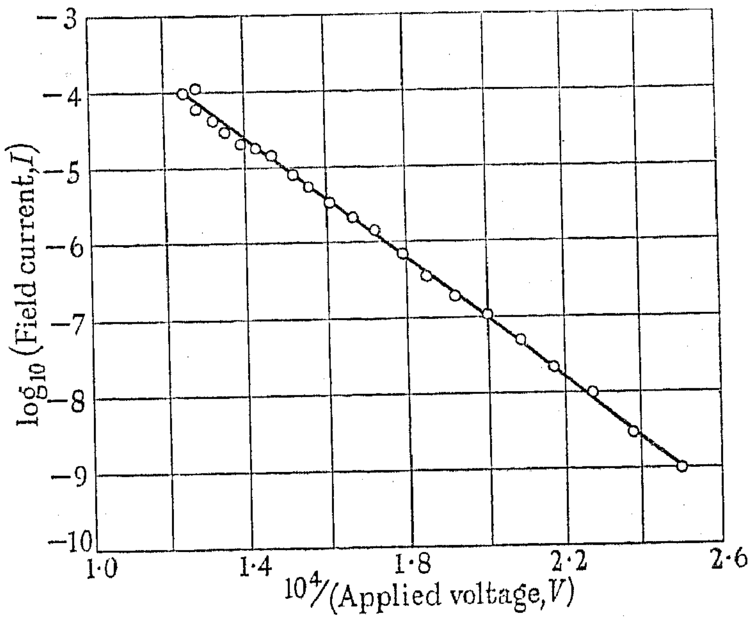


Fig. 3.—Results obtained by Millikan and Lauritsen.

Expression (4) is of the form provided by the Fowler-Nordheim theory, to be discussed later.

(3.2) Experimental Dependence on Temperature

Evidence on this point is somewhat conflicting, though only in respect of temperatures above about 1 100° K. From 300° K. up to this temperature at least it has been definitely established by Millikan and Eyring,[14] Gossling,[15] de Bruyne[24] and Ahearn[37, 42] that the field emission is independent of temperature within the limits of experimental error. Ahearn asserts that this independence, to within the same limits, extends to 1 400° K., while de Bruyne draws a similar conclusion up to 1 940° K. This latter conclusion was questioned, however, by Millikan and Lauritsen,[30] who suggested that de Bruyne's results did in fact reveal a dependence on temperature above 1 100° K. of the same small order of magnitude (a few per cent) as was indicated by Millikan and Eyring's observations in this higher temperature range. The uncertainty results from the appearance of thermionic emission of comparable magnitude at temperatures above 1 100° K. and from difficulty in assessing this latter emission to a sufficient degree of accuracy. Ahearn makes a similar claim of temperature-independence for thoriated-tungsten wires.

On the grounds of their observations Millikan and Lauritsen formulated a general relation to cover the dependence of field emission on both field strength and temperature, namely

$$I = A'''(T + cE_m)^2 \epsilon^{-\frac{b'''}{T+cE_m}} \quad . \quad . \quad . \quad (5)$$

This expression has not been confirmed, either experimentally or theoretically, though, as has been shown, it is true at low T and high E_m and degenerates into the form of the normal thermionic-emission formula at $E_m = 0$.

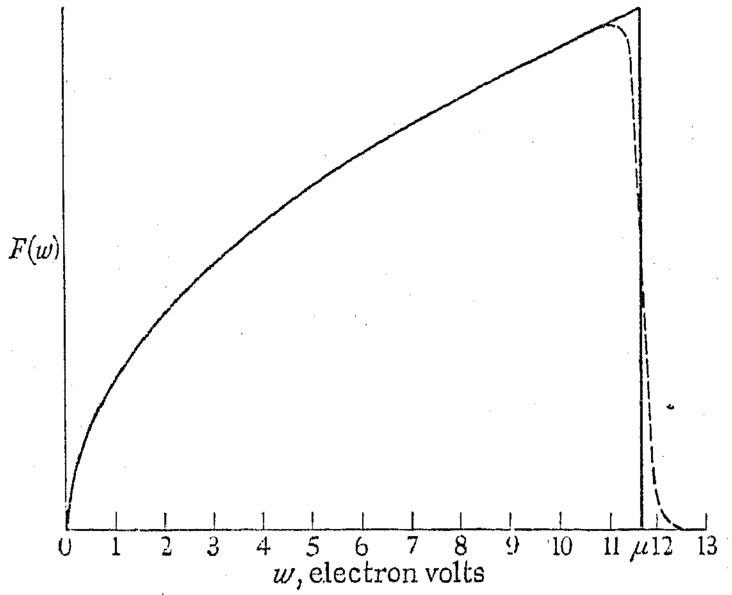


Fig. 4.—Energy distribution of free electrons in nickel at 0° K. and at 1 500° K. (Reimann).

It is of interest to mention that several experimenters have inquired whether a rise of temperature (sufficient, perhaps, to initiate thermionic emission) occurs at the emitting centres. The possibility has been disposed of by Henderson and Fleming[58] in quite recent work. Their technique was to prepare two platinum-gold thermocouples, one sharpened at the junction to a very fine point and the other left blunt, and to mount these similarly and in opposition close to the anode of a water-cooled X-ray tube. During operation, field emission occurred only at the sharp thermocouple, but with emission currents up to several milliamperes no difference of temperature between the couples could be measured within the limits of experimental error, $< 1°$ C.

(3.3) The Fowler–Nordheim Theory

The temperature-independence of field emission led to the rather natural suggestion that the electrons extracted by the field at normal temperatures differ from those which constitute thermionic emission at higher temperatures in that they do not share in the thermal energy of agitation of the atoms of the metal. This argument was developed by Millikan, Eyring and Lauritsen. The theoretical work of Fowler and Nordheim,[25] for which there is now considerable experimental support, indicates, however, that there is no such difference; and that, in fact, a single set of free or conduction electrons conforming to the Sommerfeld theory of metals and distributed in respect of their energy levels according to the statistical law of Fermi and Dirac,[64] suffices to account for both field emission and normal thermionic emission.

In Fig. 4 is shown the nature of this energy distribution for nickel at the absolute zero of temperature, represented as the relationship between the electron energy w and the " energy distribution " function $F(w)$, which expresses the number of electrons $[F(w)\delta w]$ possessing energies between the limits w and $(w + \delta w)$. It is seen that this function cuts off abruptly at an electron energy $\mu = 11 \cdot 7$ volts, which represents the maximum energy attained by an electron within the metal at 0° K. The corresponding value of μ for tungsten is $9 \cdot 2$, if it is assumed that there are 2 free electrons per atom. The effect of increase of temperature to 1 500° K. (1 227° C.) is shown in the dotted-line curve; it is to increase somewhat the maximum energy attainable by an electron, though the number permitted to possess an energy greater than $11 \cdot 7$ electron volts is only a small fraction of the total and the form of the curve is unaffected except in the region just around this energy value.

Notwithstanding the high energies possessed by some of the electrons in the metal at 0° K. and room temperature (where the energy-distribution curve differs insensibly from the full curve of Fig. 4), none of these electrons are able to escape from the surface of the metal without assistance. It is well known that the requisite assistance can be afforded by both thermal and photometric means, certain electrons being endowed thereby with a necessary additional energy χ electron volts in excess of μ, where χ is known as the " work function " of the metal. Before it can escape from the metal into free space, an electron must thus acquire a total energy $W = \mu + \chi$, a process which may be likened to that of climbing a potential hill or barrier of W volts, μ within and χ external to the metal surface. This is illustrated in Fig. 5(*a*), which relates to the case of zero external electric field. Normal thermionic emission may then be thought of as a process of " boiling " electrons over the summit of this potential barrier.

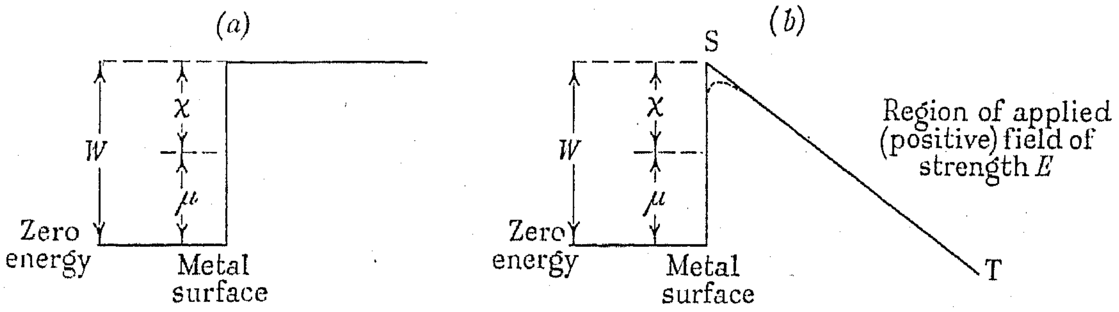


Fig. 5

In the presence of a positive external field E, however, the potential barrier encountered by an electron may be represented by Fig. 5(*b*), in which the slope of ST relative to the horizontal is a measure of the magnitude of this field. The energy which an electron must possess if it is to surmount the barrier shown in full is still $(\mu + \chi)$. Actually, the presence of the external field causes a slight rounding and reduction in height of the peak, shown dotted in Fig. 5(*b*), so that electrons of slightly lower energy may also escape, with a resulting increased thermionic emission with field strength at constant temperature. It is this effect to which the aforementioned Schottky theory relates.

At 0° K., and effectively at room temperature, however, no electron has energy in excess of μ (Fig. 4). The possibility of electrons surmounting a barrier of height $(\mu + \chi)$, or slightly less than this, does not then arise. If they are to be withdrawn from the metal surface, they must penetrate *through* the barrier. The problem to be considered, therefore, is the extent to which electrons not endowed with the additional energy χ necessary to lift them *over* the barrier may succeed in penetrating through it to provide a cold-cathode emission. Clearly, if such a process is physically possible, the magnitude of the emission will increase with the decrease in thickness of the barrier which results as the external field-strength E is increased.

The process of penetration has been described by Fowler[27] as analogous to a well-known phenomenon in optics. When a beam of light, travelling in an optically "dense" medium, is incident on the boundary between this and a lighter medium at an angle of incidence greater than the critical angle, it is totally internally reflected and no beam exists in the second medium. There is, however, an electromagnetic disturbance in the second medium which dies away exponentially with distance and which does not convey energy. In consequence, if the second medium is only a few wavelengths thick and beyond it is the first medium again, a beam of light will re-form in this and travel in the forward direction, although with much diminished amplitude. In a similar manner, for the case of a very thin potential hump of the form shown in Fig. 5(*b*), electrons incident on the face of the barrier may cause an electron stream to form on the other side, though of course of diminished magnitude, corresponding to an effective transmission of a certain number of these incident electrons through the barrier.

The mathematical problem of investigating the passage of electrons of limiting energy μ (at 0° K.) through the barrier of Fig. 5(*b*)* has been solved by Fowler and Nordheim. The solution involves two evaluations. In the first place, it is necessary to determine a function $N(w)$ expressing the number $[N(w)\delta w]$ of electrons having kinetic energies, taken *normal* to the metal surface, between the energy-limits w and $(w + \delta w)$ which strike unit area of the surface in unit time. It is then necessary to evaluate the transmission coefficient $D(w)$ of these electrons through the barrier. The electron emission density is then given by the equation

$$i = e\int_0^{\mu} N(w)D(w)\delta w \quad . \quad . \quad . \quad . \quad . \quad (6)$$

The necessary evaluations have been carried out by Fowler and Nordheim, and, after arithmetic substitution for various constants, their expression for the field current-density at 0° K. in terms of the applied field E is

$$i = 6\cdot2 \times 10^{-6}\,\frac{\mu^{\frac{1}{2}}}{(\mu + \chi)\chi^{\frac{1}{2}}}\,E^2\epsilon^{-6\cdot8 \times 10^7 \frac{\chi^{3/2}}{E}}. \quad (7)$$

in which μ and χ are in volts, E is in volts per cm., and i is in amp. per cm^2.

This expression agrees in form with the empirical relation (4). The effect of temperature is not calculated explicitly, but it is shown that this is small provided that $\mu/(kT)$, where k is Boltzmann's constant, is large, a requirement which is considered to be adequately satisfied up to normal temperatures. The question of the variation of field emission with temperature has been considered more explicitly by Houston,[28] whose mathematical work confirms that the variation to be expected is small, sufficiently small to make understandable the experimental uncertainty referred to in Section (3.2).

Some insight into the reason for the absence of an appreciable temperature-dependence may be obtained from a consideration of the curves of Fig. 4. The increase of temperature to 1 500° K. raises the energy of a certain number of electrons a part of the way beyond the energy level μ (at the most 0·8 volt) toward the top of the potential barrier, which for nickel lies 5·0 volts above the Fermi limit for μ (= 11·7 volts). Owing to the decreasing thickness of the barrier with height a greater proportion of these electrons will succeed in penetrating the barrier as compared with those of lower energy. On the other hand, the fraction of electrons raised by the temperature-increase from 0° to 1 500° K. to an energy level greater than μ is small, and since the number of electrons of energy equal to and slightly below μ is reduced thereby, it is perhaps not surprising that no appreciable increase of emission is observable up to temperatures of this order.

In considering the application of equation (7) to experimental results, it should be noted that whereas the former provides a relationship between the current density i and the true field strength E, the latter relate the total current I to a field strength $E_m (= E/\beta)$ calculated from the large-scale geometry of the electrode system. Analysis of the results in terms of (7) should therefore afford values for the emitting area A $(= I/i)$ and the coarseness factor β.

For this purpose, following Stern, Gossling and Fowler,[29] (7) may be rewritten

$$\log I = \log A - 12 + \log\frac{\mu^{\frac{1}{2}}}{(\mu + \chi)\chi^{\frac{1}{2}}} + 2\log\beta$$
$$+ 2\log E_m - 6\cdot8 \times 10^7\,\frac{\chi^{3/2}}{\beta}\,\frac{1}{E_m}. \quad . \quad (8)$$

in which A, β, μ and χ may be supposed constant.

On differentiating,

$$\frac{d(\log I/E_m^2)}{d(1/E_m)} = -\,6\cdot8 \times 10^7\,\frac{\chi^{3/2}}{\beta}. \quad . \quad . \quad (9)$$

so that β should be derived on plotting $\log\,(I/E_m^2)$ against $1/E_m$ for a surface of known work-function χ. A is then determined on substitution of the value of β so obtained in (8).

On applying these relations to the experimental data on tungsten, published by Millikan and Eyring,[14] Gossling,[15] Rother,[13] del Rosario,[16] and Millikan, Eyring and Mackeown,[19] with X assumed equal to 4·5 throughout, the calculated value of β is found to vary between 1·5 and 115, and the emitting area A from 10^{-8} to 10^{-13} cm².

---

* The slight rounding of the peak of the barrier by the external field is stated by Fowler and Nordheim to be unimportant in determining the magnitude of the field emission.

The lower of these β values correspond to surfaces which had been carefully conditioned. For such surfaces the assumption $X = 4{\cdot}5$ will be sensibly correct; for less well-conditioned surfaces, where some surface contamination by electropositive impurity might be expected, however, this value will tend to be too high and the evaluated β correspondingly too large. This, together with the less adequate smoothing-out of surface irregularities, would account in general terms for the larger of the derived β values.

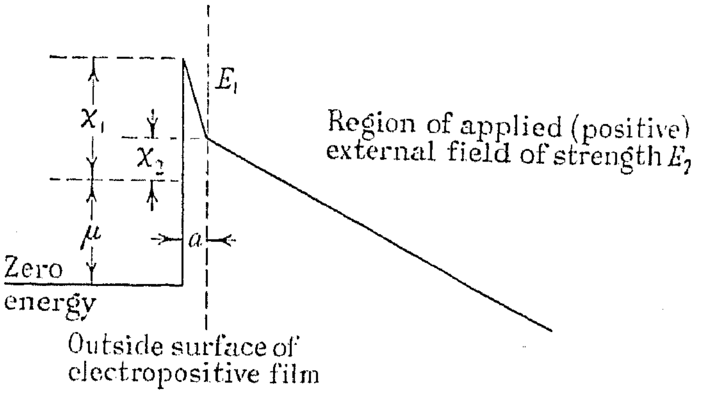

E_1
X_1
X_2
μ
a
Zero energy
Region of applied (positive) external field of strength E_2
Outside surface of electropositive film

Fig. 6

The current density, as expressed by (7), is so sensitive to change of field strength that quite small values of β in excess of unity are sufficient to account for a concentration of the emission at a few local points on the cathode surface, in keeping with the observation of scintillations. This at once accounts for the extreme smallness of the calculated emitting areas A as compared with the area of the wire surface as a whole. Areas as small as 10^{-13} cm² are, however, unlikely; they are probably under-estimates resulting likewise from the "neglect" in (7) of the effect on the emission of electropositive surface impurity, the last traces of which are extremely difficult to remove.

(4) MODIFICATION OF THE FOWLER–NORDHEIM THEORY TO TAKE ACCOUNT OF THE EFFECT OF SURFACE FILMS

When the metal is regarded as covered with a thin film of electropositive material, thickness a cm., the potential barrier encountered at the surface by the electrons of the metal may be represented as in Fig. 6. In this Figure, X_1 is the work function of the basic metal and $X_2 (< X_1)$ that of the surface film material, so that the positive field-strength within the film is given by $E_1 = (X_1 - X_2)/a$. E_2 is the applied external field-strength.

Following the same mathematical procedure as that outlined in Section (3), Stern, Gossling and Fowler[29] have derived as the modified expression for the field current-density, in amp. per cm²

$$i = \left[6{\cdot}2 \times 10^{-6} \frac{\mu^{\frac{1}{2}}}{(\mu + X_1)X_1{}^{\frac{1}{2}}} E_2^2 \epsilon^{-6{\cdot}8 \times 10^7 \frac{X_2{}^{\frac{3}{2}}}{E_2}}\right] \times \left[\frac{X_1}{X_2} \epsilon^{-6{\cdot}8 \times 10^7 a \frac{X_1 + X_2 + (X_1 X_2)^{\frac{1}{2}}}{X_1^{\frac{1}{2}} + X_2^{\frac{1}{2}}}}\right] \quad . \quad (10)$$

The results given in the Table below are reproduced from their paper and relate to the measurements of Fig. 7 on a single end of pure tungsten wire of diameter 0·002 cm. (For the purpose of calculating E_2, the end was assumed to be an ellipsoid of revolution.) The results of Curve 4, where X is taken as 4·5 volts, are for the surface after it had been conditioned by drawing large field currents from it over a prolonged period. Those associated with the lower values of X_2 relate to the surface when contaminated with sodium. The calculated thickness of the sodium film for each case is given in the column headed a; A is the emitting area, evaluated from equation (10); and A' the "apparent" emitting area, provided by the simplified equation (7). The β value stated was calculated from (9) for the film-free surface and was assumed unaffected by the sodium deposit. Since equation (10) can be written in the same form as equation (9), with the difference that X_2 replaces X, the X_2 values for the coated surfaces could then be derived from the slope of the curves of log (I/E_{2m}^2) plotted against $1/E_{2m}$ obtained experimentally (the suffix m denotes, as before, the experimental field-strength values assessed from the large-scale geometry of the electrodes).

Table

X_2	β	A	A'	a
electron volts		cm²	cm²	cm.
4·5	2·9	8×10^{-8}	8×10^{-8}	—
3·95	2·9	8×10^{-8}	$3{\cdot}9 \times 10^{-8}$	$0{\cdot}4 \times 10^{-8}$
2·85	2·9	8×10^{-8}	$4{\cdot}1 \times 10^{-9}$	$1{\cdot}8 \times 10^{-8}$
2·33	2·9	8×10^{-8}	8×10^{-10}	$2{\cdot}8 \times 10^{-8}$

The assumption of a constant value for β, and the form of equation (10), appear to be confirmed by the constancy of the calculated emitting area A. By comparison it is seen that the simpler equation (7) gives a considerable under-estimate of the area (see A') for the surfaces of lower work-function.

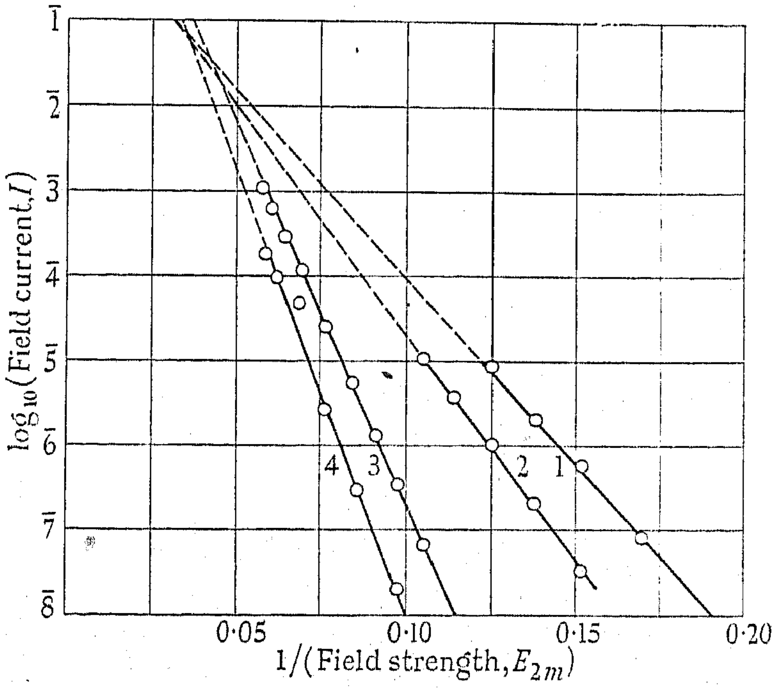


Fig. 7.—Curves due to Stern, Gossling and Fowler.

Accepting the figure of 8×10^{-8} cm² as the emitting area in these measurements, the current density over this area of the pure tungsten surface at the maximum field-strength (E_m) employed, $1\cdot 7 \times 10^7$ volts per cm., was about 2 000 amp. per cm². It is of interest to compare this with the thermionic emission density of 1 amp. per cm². from a pure tungsten filament when operated at a temperature around 2 500° K.

Müller,[51] who has studied the behaviour of tungsten points and wire coated in varying degrees with barium, magnesium and thorium, and also with caesium on tungsten oxide, preferred to determine the χ_2 values from thermionic measurements. Like Stern, Gossling and Fowler, he assumed the β value unaffected by the deposits, and in apparent contradiction of the theoretical relation (9) (with χ replaced by χ_2) his results provided the empirical relation

$$\frac{d \log (I/E_{2m}^2)}{d(1/E_{2m})} = K\chi_2^3 = \alpha \text{ (say)} \quad . \quad . \quad (11)$$

in each case. A typical set of his experimental results is given in Fig. 8.

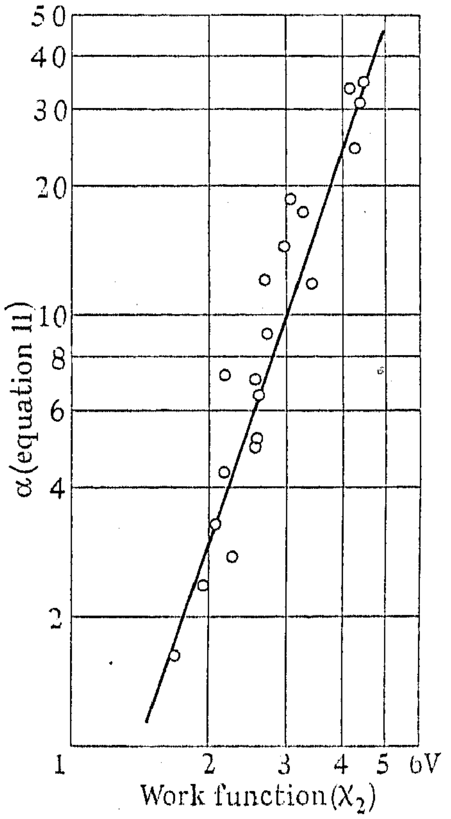


Fig. 8.—Results obtained by Müller.

The correctness of this empirical dependence of the field emission on the work function of the surface layer has been questioned by Haefer,[59] who claims that his own experiments on caesium-coated tungsten wires confirm the $\chi_2^{3/2}$ law. According to him the assumption of a constant β is valid only when the deposited film is complete and of constant thickness. Otherwise, the deposit exists in the form of small separate crystallites on which the field strength is greater than that corresponding to the tungsten base. This increase of field strength then simulates a stronger dependence of α upon the work function χ_2.

In addition to Wehnelt and Schilling,[47] Johnson and Shockley,[49] and Müller,[56] Haefer has studied the field emission from various surfaces in an electron microscope, and in support of his view concerning Müller's results he states that if barium is deposited on a tungsten point, previously emitting uniformly, the emission now arises only from individual points which must represent separate barium crystallites. For investigations of the dependence of field emission on the work function, therefore, only substances which form complete and uniform layers can rightly be employed. Haefer considers, on the grounds of his observations with the electron microscope, that caesium evaporated in sufficient quantities at room temperature is very suitable for this purpose—a complete monatomic layer is formed in about 20 min. Employing the $\chi_2^{3/2}$ relation, his results gave, as the work function for caesium on tungsten, figures between $1\cdot 35$ and $1\cdot 45$, and for compact caesium layers $1\cdot 98$, values which are in good agreement with those obtained by thermal and photo-electric methods. The χ_2^3 relation would give considerably greater values, which Haefer considers improbable. This aspect of the experimental work cannot yet be regarded as satisfactorily covered.

(4.1) Effect of Adsorbed Gases on the Field Emission

Although the effect of gases of various kinds on the thermionic emission from pure and coated tungsten cathodes has been studied extensively,[34, 64] the only systematic measurements relating directly to their effect on the field emission are a limited number made by de Bruyne.[24] In order to produce a gas-free surface as a basis, de Bruyne fused a tungsten filament in a chamber evacuated to 10^{-6} mm. and used one of the smooth-fused ends as cathode. The introduction into the test vessel for a short period of a small quantity of air produced a considerable reduction in the field emission, and a permanent loss of the original characteristic. A similar, but less marked, action was obtained with hydrogen. In their preliminary work, Millikan and Eyring observed that general heat-treatment of their electrode system (at 400°–500° C.) lowered the field strength necessary for the extraction of a specified field current. This was due, presumably, to the removal of contaminating gases from the cathode surface.

(5) ENERGY DISTRIBUTION OF THE FIELD ELECTRONS

The discussion in the preceding sections has been based on the energy distribution of electrons in metals as formulated by Fermi and Dirac and represented in Fig. 4, and on the Fowler–Nordheim analysis of the ability of electrons so distributed in energy to penetrate a thin surface-potential barrier. The most direct approach to an experimental substantiation of this physical foundation of the subject of field emission would seem, therefore, to be a study of the energy distribution of the electrons constituting this emission. This work was undertaken by Henderson and his collaborators between 1934 and 1939, and its results are of great interest.[61]

Their technique is illustrated by the schematic diagram of Fig. 9, which shows a fine wire F stretched coaxially within the two hollow cylinders, C_1 and C_2, C_1 being perforated. The potential V_1 applied between C_1 and F produces field emission from F, and a portion of the field electrons penetrates C_1 and enters the region between C_1 and C_2. C_2 is connected to F through a small, and variable, accelerating potential V_2. Electrons approaching C_2 from C_1 are thus decelerated by a potential $(V_1 - V_2)$, where

V_1 is the potential responsible for accelerating them between F and C_1.

If the argument of the preceding sections is sound, the behaviour to be anticipated is as illustrated in Fig. 10.

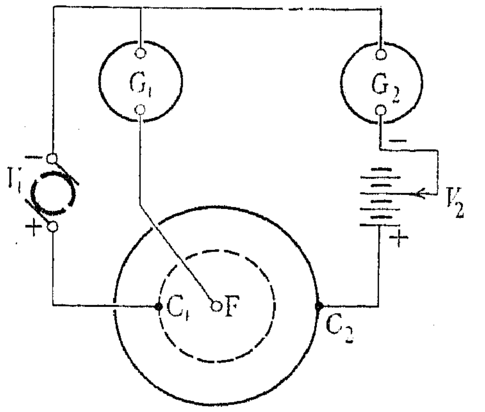


Fig. 9.—Circuit due to Henderson and Dahlstrom.

Fig. 10(a) relates to the case where $V_2 = 0$. In this case, F and C_2 being connected together directly, electrons within the two metals will attain the same maximum energy level. The horizontal dotted line arbitrarily represents this energy level. The heights of the potential barriers at the surfaces of F and C_2 above this level are the appropriate work functions χ_F and χ_{C_2}. There is a further difference, however; since the field strength at F is large the potential barrier at this surface will be thin, whereas that at C_2 being small (merely owing to the different geometry of the two electrodes), the barrier there will be correspondingly thick. Now consider an electron in F, possessing the maximum possible energy μ, which succeeds in passing *through* the thin barrier at the cathode surface. After its acceleration to C_1 and deceleration from C_1 to C_2 it will arrive at the surface of C_2 with unchanged energy. The potential barrier here is, however, too thick for penetration to be possible. The only way in which the electron can enter C_2 is in fact to pass *over* this barrier. In consequence, if the argument is sound, no electrons should be collected by C_2 until the level of the top of this barrier has been lowered relative to the upper Fermi level by an amount equal to the work function χ_{C_2} of the C_2 surface, i.e. until C_2 is lowered in potential relative to F by an amount V_2 equal to χ_{C_2}. This action is depicted in Fig. 10(b).

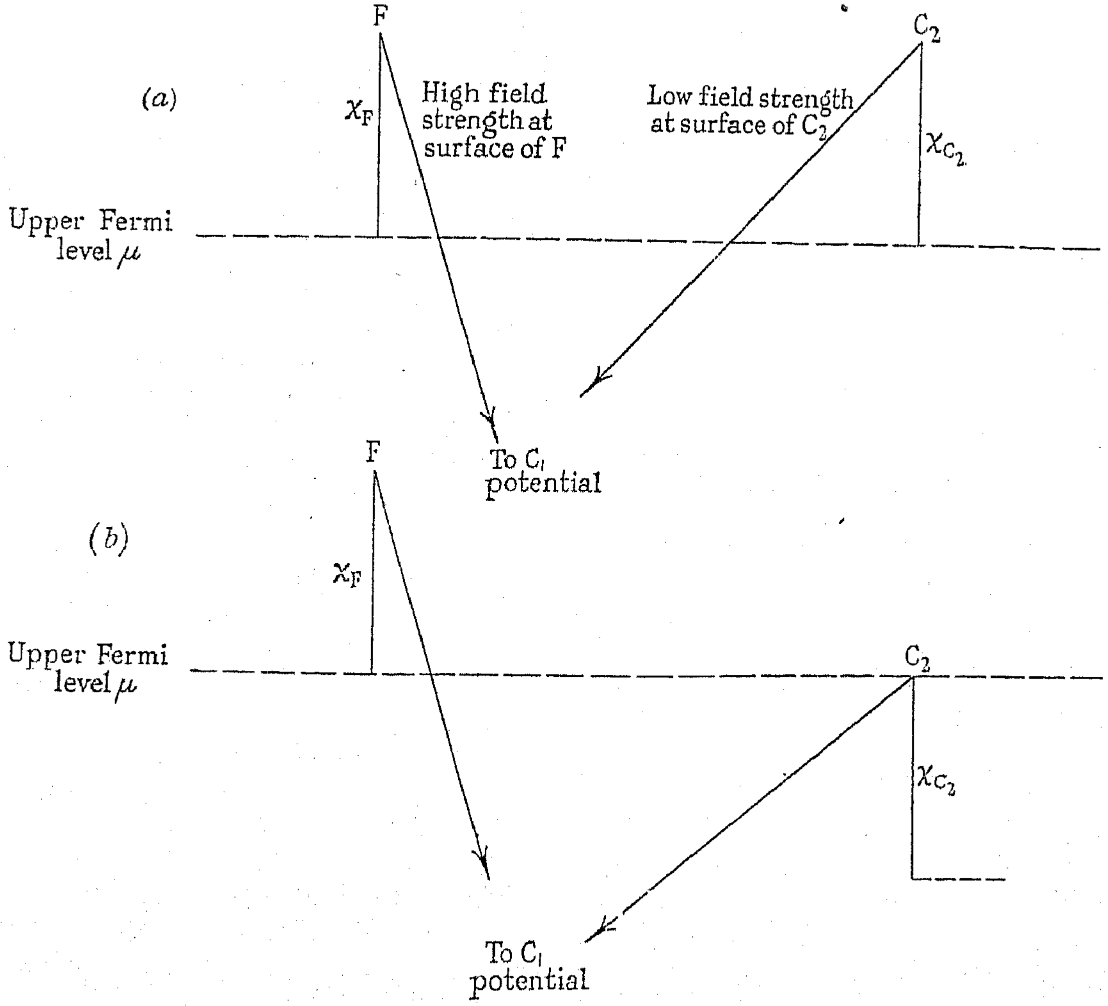


Fig. 10

(a) F and C_2 at the same potential.
(b) C_2 lowered in potential relative to F by an amount χ_{C_2}.

It is to be expected that electrons of lower energy than μ will also succeed in penetrating the barrier at F, and these will be collected as the potential of C_2 is lowered still more by further increase of V_2. The slope of the curve obtained by plotting I_2 against V_2 will represent the relative number of the emitted electrons which were associated with different energy-levels in the emitting electrode F. The plot of this slope against corresponding values of V_2 then gives the desired distribution in energy among the field electrons.

Fig. 11 shows a typical set of the energy-distribution curves obtained by Henderson and Dahlstrom for a tungsten-wire cathode at room temperature and a copper collector C_2. The three curves shown relate to different values of field strength at the cathode surface, but have been adjusted to the same maximum for purposes of comparison. It is seen that the curves rise sharply from zero at $V_2 = 4\cdot5$ volts, the work function of copper. The fact that the work function of tungsten (the cathode) is also about 4·5 volts is confusing, but this voltage value was definitely identified with the work function of the copper collector by carrying out similar measurements with a platinum emitter, a material which has a much different work function from tungsten, without change in this critical value of V_2. The rapid rise of the curves to a maximum shows that the majority of the field electrons have initial energies close to the limiting energy μ, although the spread of the curves beyond their maxima indicates a considerable range of energy below this value. The range of energy indicated, in excess of 20 volts, is, however, open to question, and two explanations are suggested by the authors, namely, that any high-energy electrons which are directed non-radially from the cathode will be recorded as electrons of lower energy; and that some of the electrons collected are the result of secondary emission from C_1. Both of these effects will tend to make the curves too high for large values of V_2. In view of these complications, the authors conclude that the results for the cylindrical-electrode arrangement employed in these measurements can be taken as reliable only in the region of the higher electron energies, corresponding to the lower V_2 values. Nevertheless, the results are in striking confirmation of the concepts on which the Fowler–Nordheim theory is based.

The fact that beyond the maxima the curves lie higher for the higher cathode field-strength values is understandable enough on this basis. Increase of this field strength, by reducing the thickness of the potential barrier at the cathode surface, should enable relatively more of the lower-energy electrons to penetrate it and take part in the emission.

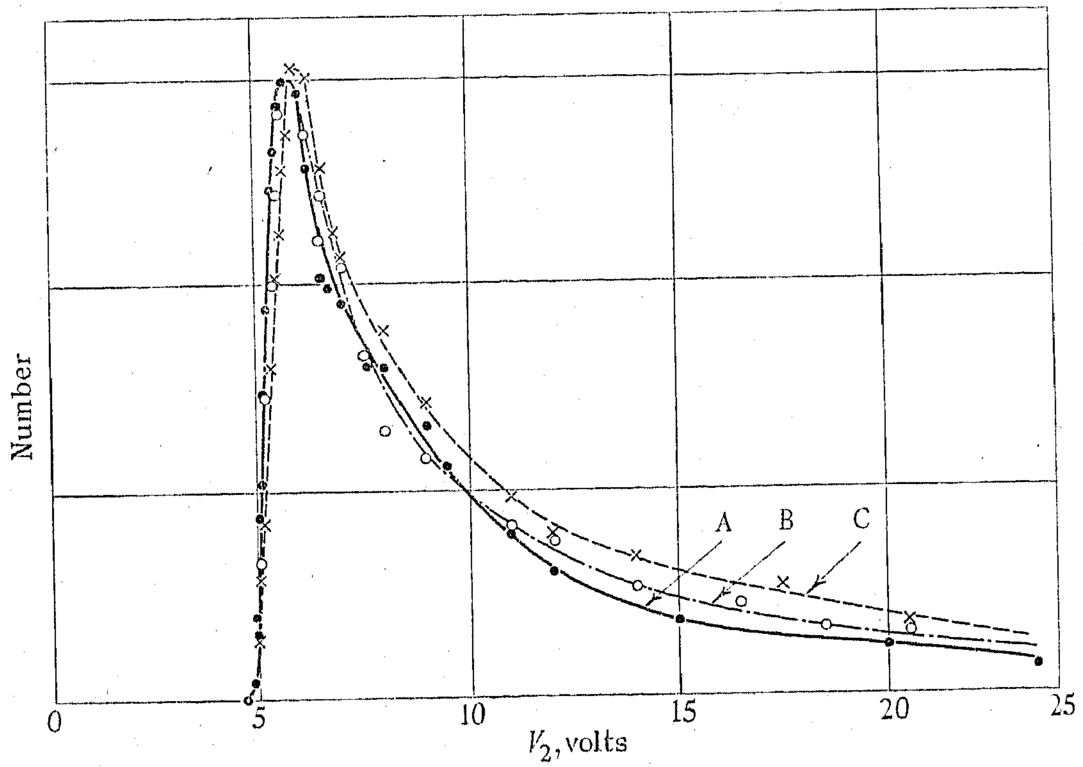


Fig. 11.—Curves due to Henderson and Dahlstrom.

A. Current $1\cdot35 \times 10^{-8}$ amp., field $6\cdot47 \times 10^5$ volts per cm.
B. Current $13\cdot5 \times 10^{-8}$ amp., field $7\cdot85 \times 10^5$ volts per cm.
C. Current 135×10^{-8} amp., field $9\cdot18 \times 10^5$ volts per cm.

(6) BREAKDOWN PHENOMENA AND TOTAL-VOLTAGE EFFECTS

In the course of increasing the voltage applied between the test electrodes, several experimenters have observed the occurrence of an "electrical breakdown" involving a spontaneous increase of the current to values as much as 10^4 to 10^7 times the pre-breakdown figure. The effect has been studied most systematically by Ahearn[42] in the course of measurements on pure tungsten and thoriated-tungsten wires. He observed that, in general, successive breakdowns on the same surface occurred at progressively higher values of the applied field—an effect which he attributed in part to the conditioning of such glass surfaces as were exposed to the discharge—and that the pre-breakdown characteristics could be largely restored by heating the cathode at about 2 600° K. for several minutes. The highest field strength (E_m) which Ahearn was able to impose on a pure tungsten surface without breakdown occurring was $4\cdot7 \times 10^6$ volts per cm.

The explanation which has usually been suggested is that the breakdown follows a rupturing of some spot on the cathode surface by positive ions produced by the original field electrons. In view of the high vacua employed these ions come presumably from the surface of either the anode or the enclosure.

Although their context is different, the results of work by Anderson[48] at voltages up to 500 000 volts on breakdown in high vacua have no doubt an important bearing on the matter. His electrodes consisted of a 1-in. sphere mounted opposite a plane, and this arrangement gave an approximately uniform field between the nearest points over a substantial range of electrode separation. The electrodes were conditioned in an atmosphere of hydrogen at a pressure of 1 mm. Hg by the passage of a discharge between them of current density about 0·25 amp. per cm². for a period of 3 minutes. Following this, the container was evacuated to 10^{-5} mm. and frequent sparkovers were produced with an electrostatic generator. The result was a final breakdown voltage more than double that at which sparkover first occurred.

Anderson's results on steel electrodes, which, of steel, nickel, Monel metal, aluminium and copper, gave the highest breakdown figures, in this order, for variable separation are reproduced in Fig. 12. The observation that increased inter-electrode separation and voltage is accompanied by breakdown at reduced field-strengths, indicates that the current which precedes breakdown, and which presumably originates as field emission from the cathode, involves other factors beside the cathode gradient. Since the degree of vacuum employed was well above that at which the results ceased to depend on the gas pressure, the explanation investigated was that of positive-ion emission from the anode with resulting bombardment of the cathode and consequent electronic emission therefrom at lower field-strengths.

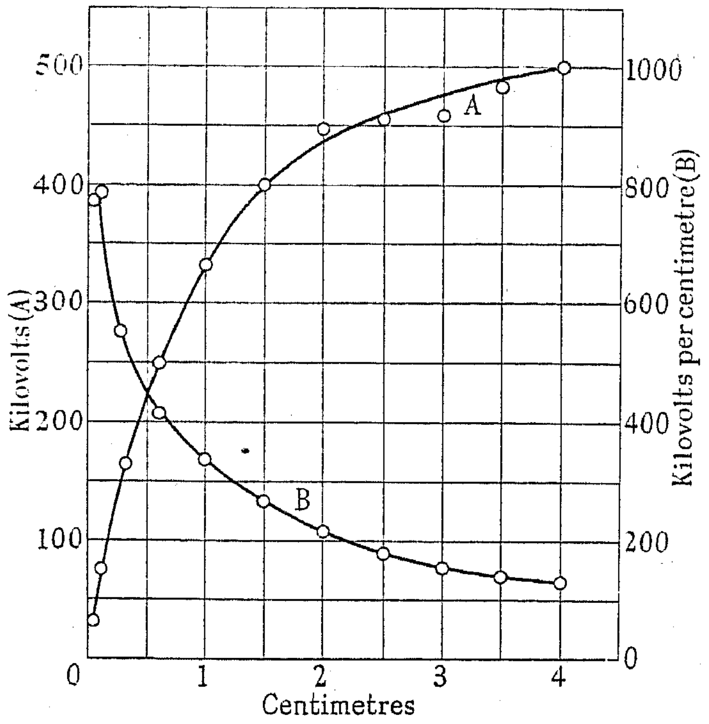


Fig. 12.—Results due to Anderson.

For the purpose of checking this hypothesis, two series of experiments were performed:—

(*a*) Electrodes of different materials were used to determine whether anode material actually is deposited upon the cathode; this would be the case if positive ions from it played a part in the conduction.

(*b*) The inter-electrode current was measured in a region of uniform field and constant electrode area as the voltage and electrode separation were increased, but so as to give constant field-strength at the cathode surface.

Measurements with a steel cathode and copper anode in the first series of experiments showed that particles from the anode were in fact being deposited on the cathode. The results of the second series are reproduced in Fig. 13 and show convincingly that, for voltages of the high order employed, the inter-electrode current varies substantially with voltage during the maintenance of a constant field-strength at the cathode (the average gradient in kV per cm. is marked on the curves). For this action the term "total-voltage effect" has been suggested.

The voltages employed for the production of the requisite field strengths in the investigations discussed previously were substantially less than those involved in Anderson's work, so that this effect was presumably insignificant. The surprisingly low cathode voltage-gradients at which substantial field currents were observed in the million-volt X-ray tube described by Allibone, Bancroft and Innes[62] point, however, to the operation of this effect. According to Fig. 12, *breakdown* of a 4-cm. gap occurred at a field strength of 120 kV per cm. and a total voltage of 500 kV. With an electrode separation of 12·5 cm. and the same inter-electrode voltage in the X-ray tube mentioned, the field currents had become sufficiently large to limit operation—but not to constitute a breakdown—at a cathode gradient of 57 kV per cm. at the filament end and of 22 kV per cm. at the anode end of the tube. Adequate information to provide a satisfactory explanation of the latter figure in particular is, however, lacking.

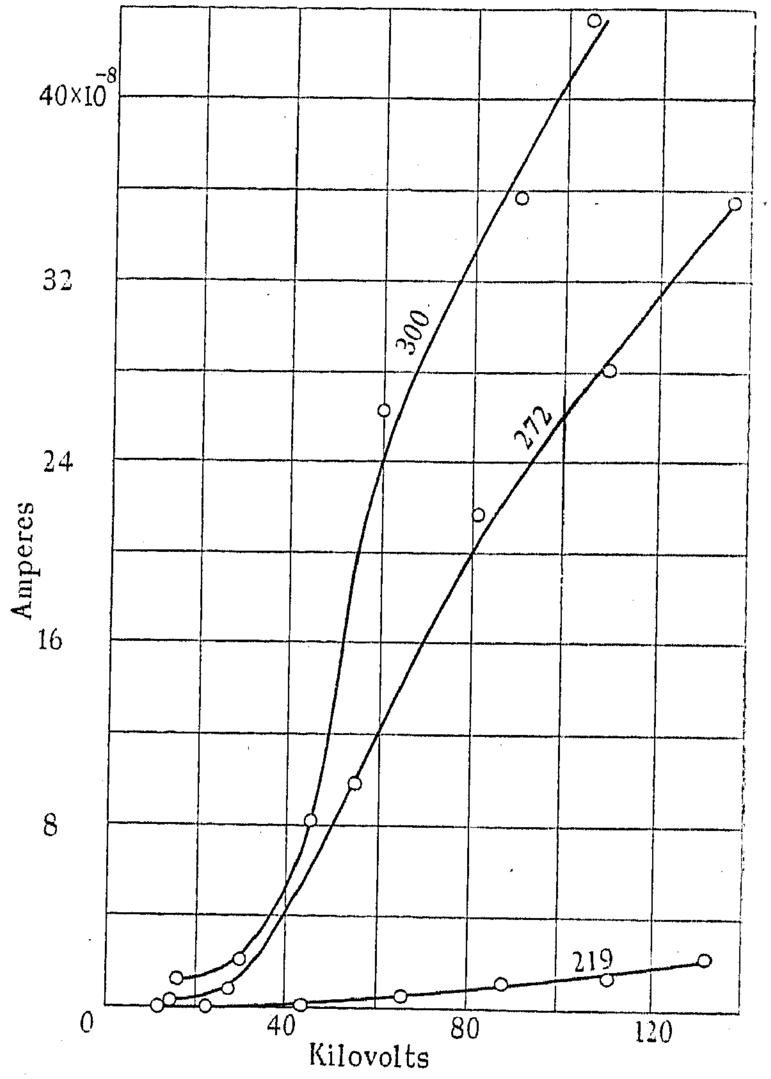


Fig. 13.—Results due to Anderson.

(7) THE MERCURY CATHODE

The two difficulties inherent in the attempts to correlate the results of experiment with the Fowler–Nordheim theory quantitatively have been inability to determine directly the effective field-strength at the metal surface due to microscopic or sub-microscopic irregularities thereon, and lack of knowledge of the dimensions of the emitting area. It seemed to Beams[38] that the first difficulty, at any rate, might be overcome by studying the action of highly purified liquid mercury. His investigation has a wider significance, however, in view of the suggestion put forward by Langmuir,[12] and supported by Compton and his collaborators, that the current in the mercury-arc discharge is predominantly electronic and originates as field emission from the cathode spot.

It appears that the phenomenon at the mercury cathode is as follows:[41] The current density is about 4 000 amp. per cm^2, of which at least 80 %, and probably 95 %, is carried by electrons. The remaining 5 % to 20 % is carried by positive ions, which form a positive space charge in front of the cathode sufficient to produce an electric field of the order of 10^5 volts per cm. at the cathode surface. It has been seen that this order of field strength is adequate to extract considerable field currents from metal surfaces of normal roughness in high vacuum. If the mercury surface is structurally smooth, as might reasonably be expected for a clean surface, much higher field-strengths should be necessary for the initiation of a discharge: on the other hand, once initiated, the agitation of the mercury surface might well provoke very high local field-strengths adequate to account for the current magnitudes observed. The results of Beam's work are therefore of special interest.

In view of the fact that field strengths of the order of 10^5–10^6 volts per cm. will generate mechanical forces of sufficient strength when applied locally to produce considerable distortion of the mercury surface, Beams adopted an experimental technique involving the application of the electric field for so short a time, 10^{-6} sec., that it could develop no appreciable surface distortion.

His observations were that for a single distillation of the mercury the field necessary to initiate a discharge between the surface and an adjacent spherical anode was $6\cdot5 \times 10^5$ volts per cm., but that this field increased with repeated distillations to a maximum figure of $1\cdot8 \times 10^6$ volts per cm. The current density in the discharge was estimated at 1 amp. per cm^2. Contrary to expectation, these figures indicate considerable surface roughness; in fact, using equation (7) Beams estimates a value of β equal to 18, a figure which is surprisingly high in view of the care exercised in purification of the mercury. It suggests that the space-charge field strengths estimated by Compton and Langmuir[32] are probably quite adequate to support the arc in the practical case, where the mercury must surely carry a certain amount of surface impurity. Beams observed, for example, that water vapour and grease vapours lowered the field strength required for the initiation of a discharge to $3\cdot5 \times 10^5$ volts per cm. Subsequent work by Quarles,[43] Tonks and Moore[53] on the same subject confirm but add little to the above information.

(8) THIN-FILM FIELD EMISSION, AND A POSSIBLE EXPLANATION OF THE BEHAVIOUR OF THYRITE

A new aspect of the phenomenon of field emission has been revealed by Malter[52] in the course of recent work on secondary emission from metallic surfaces. In his search for a surface possessing a specially high secondary-emission ratio, he found that it was possible to obtain from an aluminium-oxide surface, suitably treated with caesium and oxygen, a current several thousand times as large as the primary current. The phenomenon differs from that of normal secondary emission in that the current extracted increases rapidly with the potential of the collector electrode. The empirical law relating the collector current and potential was found to be:—

$$I_c = K(V_c)^m \qquad (12)$$

where m is of the order of 3. The collector current also varied with the density of the primary beam.

The explanation given is that on impinging upon the treated aluminium-oxide surface the primary electrons cause the release of normal secondary electrons. These are attracted to the collector electrode. For a secondary-emission ratio greater than unity and a film of high resistivity, however, there will occur a gradual accumulation of positive charge on the oxide surface, and the establishment of a potential difference between the outer surface of the film and the basic metal on which it is deposited. It is supposed that with the thin films in question (thickness about 2 000 Å) this potential difference produces field strengths at the metal surface sufficient for the extraction from it of field electrons, and that it is these which constitute the exaggerated secondary beam.

The removal of the primary beam does not result in immediate cessation of this field emission, nor, therefore, of the collector current, but rather in a slow decay corresponding to the gradual leaking-away of the accumulated positive surface charge. The surface was found to be photo-sensitive, in that light caused a decrease both in the emission and in this time-lag characteristic.

The phenomenon appears to be closely related to one described by Güntherschulze,[39] who discovered that extremely fine particles of aluminium oxide sprinkled on a semi-conductor, employed as the cathode of a gas discharge tube, caused the emission of a very copious stream of electrons.

The relation between collector current and collector voltage given in (12) is of special interest since it is of the same form as that relating current and voltage for the non-linear material known as Thyrite. This material is composed of carborundum, coated with silica, embedded in a high-resistance matrix. Güntherschulze, prior to the date of Malter's work, had in fact already ascribed the behaviour of this material to the establishment of high potential-gradients between the carborundum particles and the occurrence of field emission at their surfaces, a conclusion which appears to be borne out by the above observations.

Convincing support of Malter's explanation of the physical mechanism involved in his effect has been given by Mahl,[57] who has measured the potential difference developed across the oxide film and found it to lie between 10 and 50 volts. This corresponds, for films of thickness 2 000 Å, to a field strength at the metal surface of the order of 5×10^5 to 25×10^5 volts per cm., a figure quite high enough to account for field emission. Moreover, Mahl has shown that the energy distribution of the emitted electrons is analogous to that discussed in Section (5).

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ABSTRACTS OF PAPERS

ELECTRICITY IN PAPER MILLS

By W. J. Mason and S. A. G. Emms, B.Sc.*

(Abstract *of a paper which will be published in October, in Part II of the Journal.*)

All forms of paper are made from cellulose, which is the structural basis of the vegetable world. The materials mainly used are wood, esparto grass, rags and, to-day, straw. Wood is received in this country in pulp form, whilst the other materials require treatment with chemicals and steam to separate the fibres from lignins, etc. The separated fibres are beaten and brushed in water for a period varying from 20 minutes to several hours, depending on the class of paper required. This action causes the fibres to be hydrated, so that they will felt together and eventually reform into a homogeneous substance.

The paper machine is a device for forming an even, level sheet and extracting the unwanted water of formation by indrawing, pressing and evaporation. The couch section is a gauze wire table on which the diluted stock flows, and here the water is removed by drainage assisted by vacuum boxes, followed by pairs of rollers called presses, in which further water is removed by pressure and, finally, evaporation on the steam-heated dryers.

Typical power, steam and water requirements for a few general classes of paper are given in Table 1.

Table 1

Average Air, Water, Steam and Power Requirements for Paper Mills per Ton of Paper

	Rag papers	Esparto papers	Newsprint
Steam for drying and heating (5–20 lb./sq. in. gauge) ..	3·5–4·5 tons	3·5–4·5 tons	3·5–4·5 tons
Steam for cooking and recovery (50–60 lb./sq. in. gauge) ..	2·5–3·0 tons	4·5–5·0 tons	—
Water (100–150 ft. head)	350–400 tons	300–350 tons	150–200 tons
Air (4–10 in. water gauge)	50–65 tons	50–65 tons	100–150 tons
Power for preparation plant	800–1 000 kWh	450–500 kWh	150–200 kWh
Power for paper machine drive	50–70 kWh	50–70 kWh	90–100 kWh
Power for paper machine pumps and auxiliaries	120–180 kWh	120–180 kWh	150–200 kWh
Power for finishing room	15–20 kWh	15–20 kWh	60–100 kWh
Power for cranes, conveyors, etc.	20–25 kWh	25–30 kWh	35–50 kWh
Power for lighting	6–10 kWh	8–10 kWh	8–10 kWh

The power plant has to produce power and low-pressure steam for heating and drying, and, in the case of mills using grass and rags, a supply of medium-pressure steam is necessary intermittently for cooking raw materials. To meet these conditions power plant must be installed in the mill, and such plant to-day consists of pass-out turbines, having one or two pass-out pressures. For small mills the double-pass-out turbine hardly justifies the extra cost and complications unless the power demand is exceptionally great. A comparison of the two methods for similar conditions is shown in a Table in the paper.

The choice of a.c. or d.c. power supply when electrifying is a thorny one in the case of existing mills, and in nearly every instance the existing supply has been extended. For large new mills alternating current would to-day be installed, and either a.c. commutator motors, or motor-generators, or rectifiers, would be used for the variable-speed drives. In the past, 500 volts alternating current has been used, but with reduction in switch ratings as in B.S. No. 116—1937, higher voltages for powers of 2 000 kW and over will be necessary or the plant will have to be sub-divided. The voltage chosen and the switchgear installed should have a margin over present demands to cover extensions.

Motor and Control Gear

No special mention need be made except to reiterate that all plant should be liberally rated, and of robust construction, as it has to run continuously for 132 hours per week, with only a short time at week-ends for maintenance, and the stoppage of one motor will hold up the production of that section of the mill.

Drives for Paper Machine Auxiliaries

Associated with the paper machine are a number of auxiliary drives for pumps, which require infrequent starting, and a description is given of a system of control (plural starting) which meets all requirements, giving full protection, has lower first cost than hand-operated individual starters, and enables the starting gear to be placed away from the wet end of the machine. The only apparatus required near the motors is a push-button control station with an ammeter. In most mills space at the wet end is restricted, and it is often difficult to accommodate individual starters near the motor. This system of plural starting has two starters, the motors normally being split between them. If necessary, any one starter can be used for all motor circuits.

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* General Electric Co., Ltd.

Paper Machine Drives

The paper machines are the largest and most important in the mill, and are to-day invariably driven sectionally by a motor on each section, the number of motors being from 6 to 12 or more.

The paper on passing through the machine is elongated by 5 to 8 %, which is divided unequally between sections; this elongation is termed "draw." The draw varies with different treatment of stock, and means have to be provided to drive the sections at slightly different speeds and to vary these whilst running, and, when set, they must not vary for changes in the load or temperature, otherwise the fragile paper will be strained, if not broken.

The intersectional speed is held by a draw regulator. These all work on the differential principle of comparing the angular velocity of a master frequency or speed against the roll velocity. Any angular positional errors are integrated and are used to correct the speed.

There are four types of draw regulators in use in this country. Types (a) and (b) use mechanical differential gearing, one element being driven by the section motor through a small cone belt-drive to allow of draw adjustment, and the other from the master reference speed, any difference between the two being transferred to a rheostat varying the section motor field. Type (a) has a light master-shaft running the full length of the machine, whilst in (b) this is replaced by small synchronous motors forming an electrical master-shaft.

Type (c) is an electrical differential consisting of a wound 3-phase stator and rotor with exciting winding. The stator is supplied from the master frequency supply, and the motor is driven through a draw-adjusting belt by the section motor. The difference in speed causes the stator to rotate and to correct the error.

Type (d) is an electrical differential with 3-phase windings on both the stator and the rotor, the stator being fed from the master frequency set, and the rotor from a small 3-phase alternator driven by a draw-adjusting belt by the section motor; with equal frequency the rotor is stationary. With this arrangement the draw regulator can be placed on the switchboard or in any other convenient place.

The maximum error that can be permitted between sections is a vital quantity if the paper web is not to be strained, and this calls for a regulator that is sensitive and a rapid response of the section motor to the regulator displacement.

Drives call for a variable speed of from 2/1 to 10/1; and, in addition, a crawling speed of 60–70 ft. per min. is necessary for the examination of wire and felts. In d.c. drives the main speed variation is obtained from a.c. or d.c. convertor sets, and the crawling speed by armature resistance or separate low-voltage generator, which is also used for starting. With a.c. drives this is done by a separate barring motor and gearing.

The starting torque on dryers and calender sections is high, and is normal on the couch, the presses and the reel.

The power required at various speeds for a 3-roll machine (i.e. 230 in. wide) is given in Fig. 1.

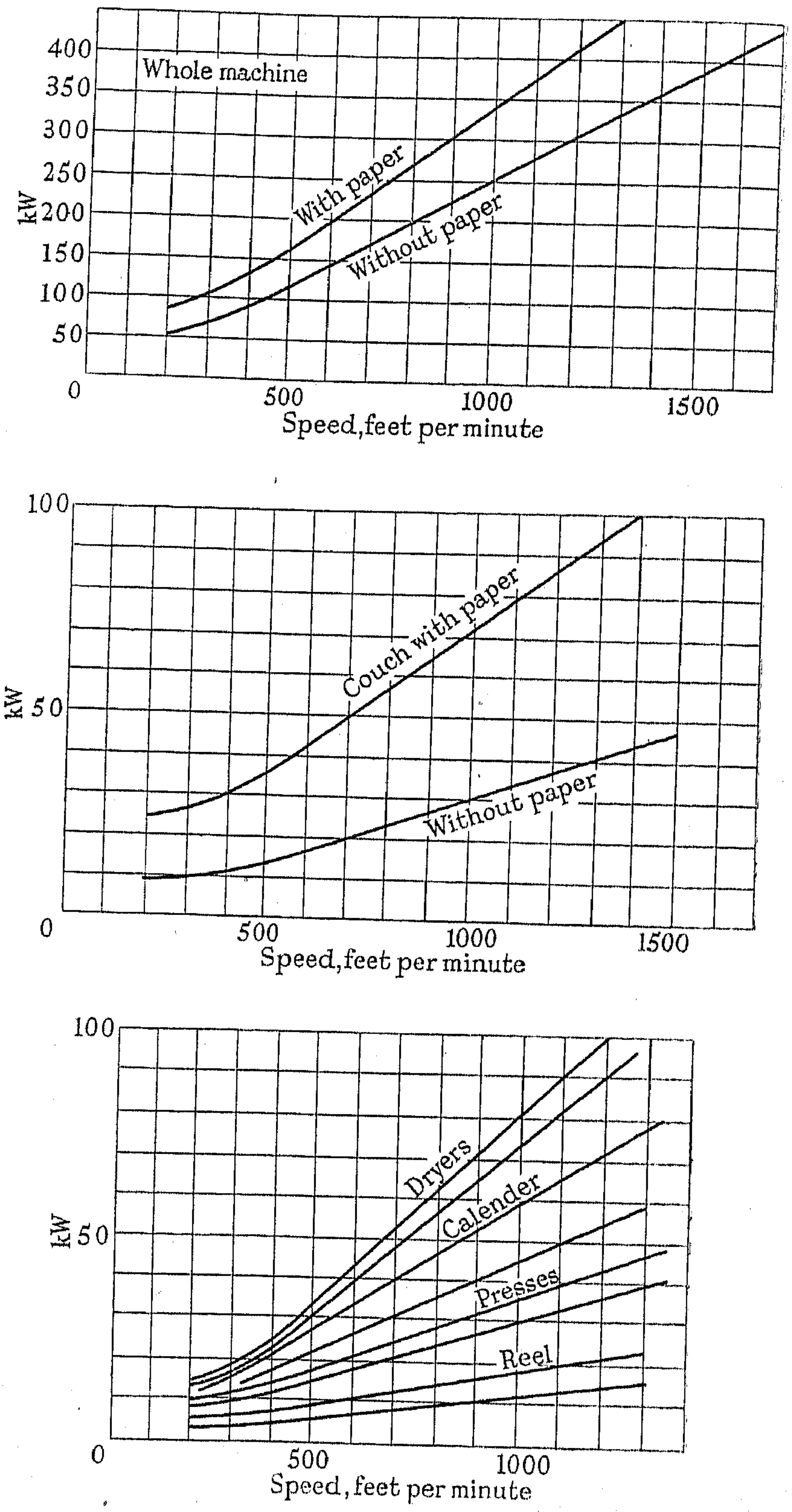

Fig. 1.—Input (kW) at various speeds of a 3-roll machine.

Speed Control of Whole Machine

The holding of the paper machine speed constant is important, as the weight of the paper depends on the speed. These speed-changes can be caused by variations in the torque or the temperature in the drive, or externally by voltage or frequency variations in the mill supply; the former occur slowly whilst the latter, although slight, are rapid. Any method used must be capable of meeting both conditions over the whole speed range of the drive.

A method which has been used successfully depends on the comparison of two voltages, one proportional to the paper speed and the other to a standard voltage obtained from a lamp bridge. (A diagram is shown in the paper.) The lamp bridge, when made up of a suitable proportion of metal-filament and carbon-filament lamps, has the property of giving a constant voltage at the output terminals over a wide range of voltage applied to the input terminals. The two voltages are compared by means of a supersensitive relay, which will operate with a difference in the two circuits of less than 1 microwatt, and will hold the speed of the paper within ± 0·3 %.

Super-Calender and Winder

If a better surface is required, the paper after leaving the paper machine is passed through a super-calender, which is similar to the machine calender, but alternate rolls are made of compressed paper or cotton. The drive between the rolls is frictional, and the slip between them produces the calendering effect. In operation the paper is fed by hand through the rolls at low speeds, and is finally taken to the reeling-up roll, after which additional pressure is applied by means of weights and the paper is accelerated up to full speed. To avoid breaking the paper it is essential that the acceleration be as gentle as possible, a large number of starting steps being needed.

Should the paper break, the machine has to be brought to rest promptly without pressure on the rolls, otherwise the soft rolls will be dented and even damaged; even the weight of the rolls alone causes some deformation—the extent depending on how long the calender is standing—giving a variable starting torque, which necessitates that the motor shall be capable of starting against heavy overload torques, whilst the normal crawling speed must not be exceeded. A low-voltage motor-generator with d.c. drives is frequently provided to supply the heavy current. A method is described which starts the calender smoothly under all conditions and gives the normal crawling or feeding-up speed.

Winder

After super-calendering, the paper passes to the winder, where it is trimmed to the correct width and all bad places are made good. High-speed printing demands continuous rolls of paper wound at constant tension. Attention has recently been given to obtaining this automatically by means of a braking generator driven by the unreeling paper, in place of the mechanical friction brake used hitherto and operated by the winder man. When winder-driven with a Ward–Leonard set, the regenerative brake is easy to apply and the constant-current regulator is satisfactory whilst running at fixed speeds; during acceleration and retardation some form of compensation must be applied if the tension is to be kept constant, as the inertia of the unreeling drum progressively declines.

A fixed compensation cannot be used, as the size of the reels varies; also the reels are frequently started and stopped for removing faulty paper, and constant tension is required throughout the reel.

Electricity is used for lighting, in addition to the heavy power, and photo-electric cells are employed for many applications. References are given in the paper to available information on these applications.

THE CONTROL OF THE DOMESTIC LOAD

By P. Schiller.

(Abstract *of a paper which will be published in October, in Part II of the Journal.*)

The development of a thermal load fundamentally changes the aspects of the domestic supply, for this component of the domestic load far outweighs the until recently preponderating lighting component. Its influence on the load curve is reflected in the transfer of the incidence of the system peak from the late afternoon or evening to midday or morning, frequently to a Sunday midday, and in increasing susceptibility to variations in the temperature of the open air. The latter feature is due to the fact that the offering of low unit charges under the domestic two-part tariff, primarily intended to cultivate electric cooking and water heating, is actually creating a far more pronounced seasonal radiator load. As average winter temperatures are comparatively moderate in this country, conventional space-heating installations based on the combustion of solid fuel have, as a rule, not been designed to cope with occasional spells of cold weather. In consequence electric radiators are increasingly used to supplement these inadequate installations during such cold snaps, which are generally of very limited duration.

The results can be seen from Fig. 1 in which are reproduced comparative load curves of the Wimbledon undertaking as recorded on two winter weekdays only one week apart. The curve drawn in full lines shows the difference between the loads on the two days. Considering that there was probably also a certain amount of space-heating load on the warmer day, it appears that appreciably over half of the maximum demand on the particular undertaking was due to electric space heating, causing the magnitude of the peak to vary in a ratio of almost 1 : 2 within a week. Plant capacity including necessary reserves has to be provided to cope with the possible maximum demand during a cold snap, a contingency that may or may not occur for years.

The early part of 1940 brought cold snaps which had particularly serious consequences. Undertakings reported that the load on some substations had risen to three times the normal winter demand. Numerous failures of the electricity supply due to overloading were experienced. The whole Grid system had to be stressed almost beyond the limit, making it impossible for some time to maintain the frequency at the constant value required for accurate clock operation.

Were it not for the war, the connection to the mains of

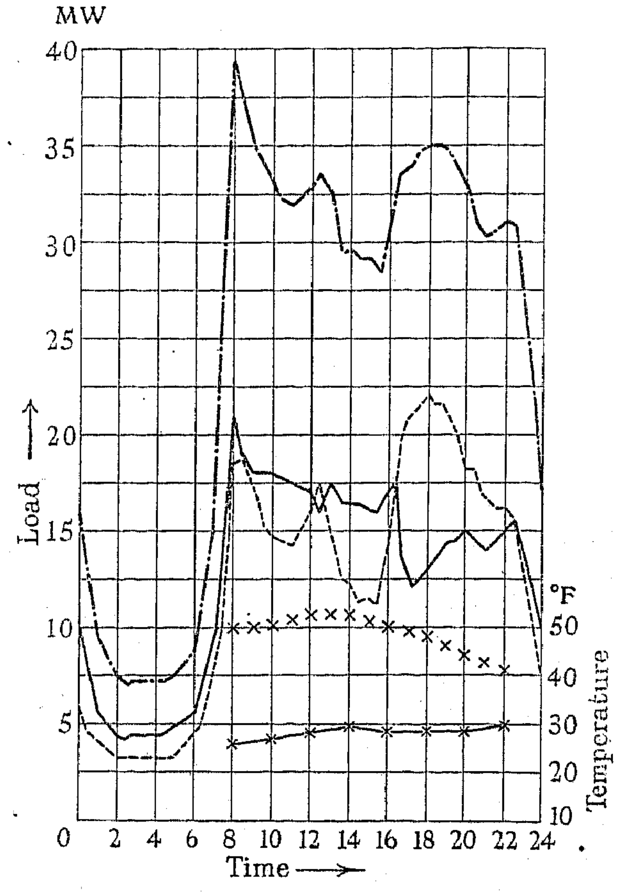

Fig. 1.—Influence of a cold snap on the load of an undertaking with preponderating domestic load.

—— – —— Load } Wednesday, 21st December, 1938.
—— × —— Temperature }
— — — — Load } Wednesday, 14th December, 1938.
× × × Temperature }
———— Difference in load.

thousands of additional radiators would still be continuing, and by now conditions might well be getting beyond control.

The effect this development had on the load factor of undertakings supplying a preponderating domestic load is illustrated in Fig. 2. It will be seen that the building up of a morning and midday load due to the intensified connection of thermal appliances had originally a beneficial effect, though this was soon accompanied by a marked sensitivity to winter temperatures, first noticeable in the results for 1928–29. The recent trend, however, appears to be one of decline, attributable to the growing preponderance of the radiator load.

Once the system peak occurs at a time characteristic of the domestic thermal load, there can no longer be any illusion as to the real load factor of the latter, which is then definitely not higher than 30 % and apparently apt to deteriorate. A load factor of this magnitude does not appear to justify the low prices now charged for the supply of the domestic thermal load, whilst these are generally still too high to allow consumers of the lower-income classes to make liberal use of electricity for at least cooking and water-heating.

The solution can only be found in substantially raising the load factor of the domestic thermal load, and this necessitates cultivation of thermal-storage methods accompanied by load control.

A new system of load control, called "demand control," limits the aggregate demand of all the restricted appliances of a consumer's installation to a value that can be varied by means of centralized remote-control in accordance with the requirements of the supply undertaking. If the load of the installation exceeds the instantaneous demand limit the restricted appliances are periodically disconnected and reconnected in a cyclic manner, so that the resultant mean load is maintained at that limit. Advantage is thus taken of the well-known principle of controlling the effective output of a heating circuit by periodic interruption of the supply. During periods of restriction a certain limited amount of power is now put at the disposal of the consumer, which he is free to use as he thinks fit, though the power available for the restricted appliances is diminished by the simultaneous demand of the unrestricted portion of the installation.

Fig. 3 shows a circuit diagram of a consumer's installation equipped for demand control. The control unit A includes a receiving relay for varying the demand limit by centralized control, and operates a contactor B. The restricted circuits are supposed to comprise those serving the permanently connected appliances for water and space heating, and those supplying the power socket-outlets for portable radiators, etc. The cooker circuit is supposed to be left unrestricted. C indicates an optional miniature circuit-breaker provided with a view to discouraging the plugging of powerful heating appliances into lighting sockets in circumvention of the restriction arrangement.

In addition to the receiving relay, the demand control unit comprises a metering element which, while serving for registering the consumption of the installation, also drives a sun wheel of a differential, the other sun wheel of the latter being driven at variable speed from a small motor of the clock type. The speed of the second sun wheel at any moment determines the demand limit at that moment. The planet portion of the differential operates the contactor B. Standard receiving relays as used for the peak-period disconnection of water heaters can be applied for varying the speed of the second sun wheel by centralized control. Thus the costs of a demand control unit are virtually composed of the extra cost of modifying a standard house service meter, and those of the contactor and standard receiving relay.

Following the well-established principles of two-part costing in electricity supply, the variable share in demand allotted to each controlled consumer can be made a function of his contribution in the way of fixed charge. Existing methods of assessing the latter can be retained. The yearly amount thus resulting is converted into a "service rating" by division into a certain constant representing kilowatts per pound sterling. Each consumer's service rating determines the highest setting of his demand control unit. Any desired higher service rating may be obtained by subscribing a proportionally increased fixed charge. The variation of the consumers' demand limits by centralized control is effected simultaneously for all controlled consumers, whereby the relative degree of availability, i.e. the ratio of instantaneous demand limit to service rating, is always equal for all such consumers. It is obvious that if the demand limit is lowered from the maximum in order to curtail the supply to the controlled load of a system, this will affect consumers in the order of their instantaneous relative demands, i.e. diversity in instantaneous demand still plays a certain role.

In order that all the controlled consumers of a system

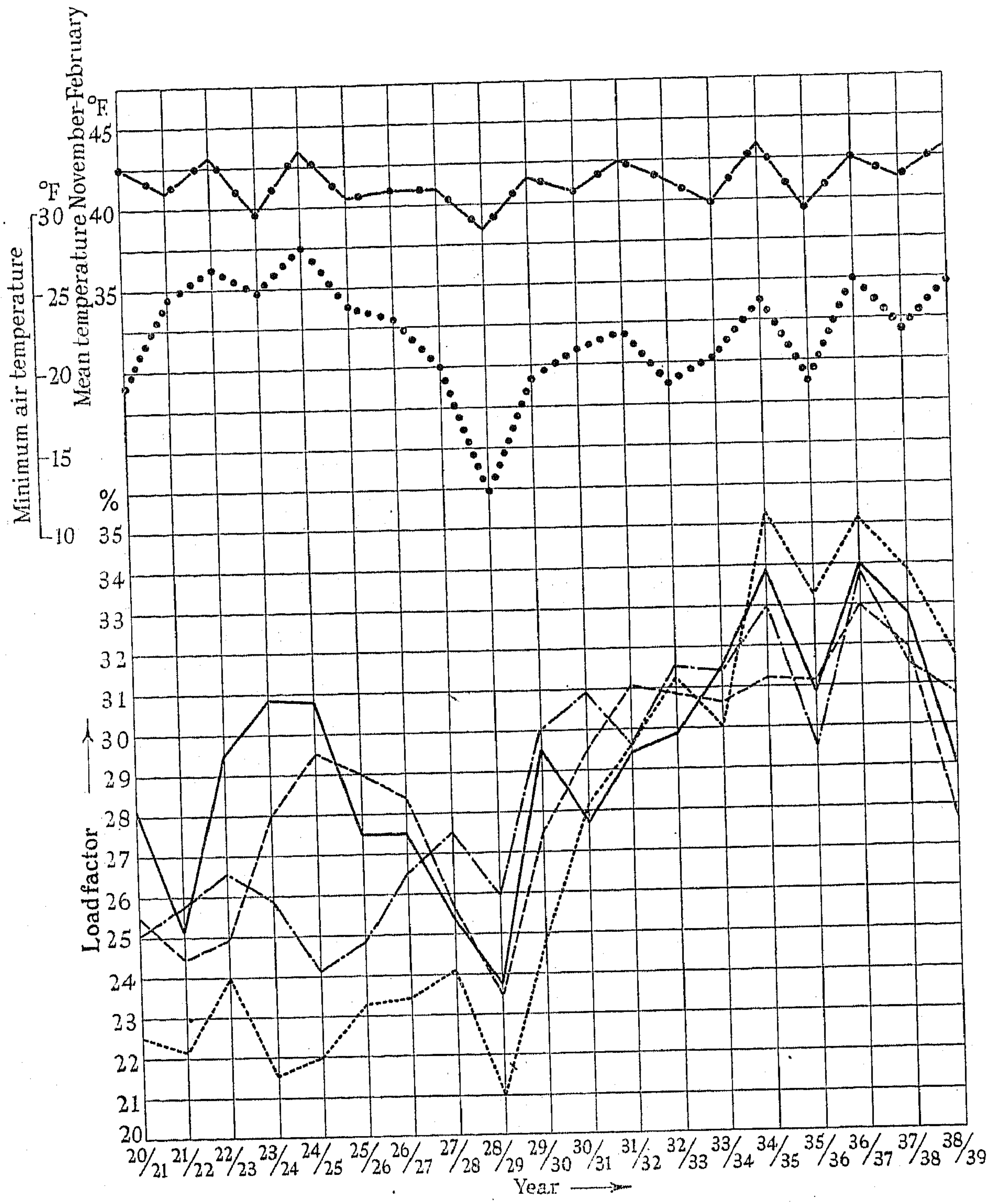

Fig. 2.—Development of the load factor of 4 undertakings with preponderating domestic load.

— • — Mean air temperature for November to February (Southport).
• • • • • Minimum air temperature for November to February (Southport).
——— Load factor of Beckenham undertaking.
- - - - - Load factor of Harrogate undertaking.
— - — Load factor of Southport undertaking.
— — — Load factor of Wimbledon undertaking.

may be treated equally, it is preferable to centralize the control at a single point of a complete supply system, such as a generating or bulk-supply station.

Each consumer is guaranteed certain minimum values of power which will be available for his restricted appliances at various times of day, though there may be periods when the minimum is zero. If expressed as a percentage of the service rating the minima are the same for all controlled consumers of a system. The supply undertaking will, of course, always endeavour to keep the supply above these minima so as to sell the maximum number of units compatible with system load.

The consumer can see the actual demand limit at his disposal at any particular moment from an indicator on his demand control unit. A similar indicator, but with percentage scale, is installed at the control centre and keeps the system operator aware of the instantaneous setting of the consumers' control units. On the basis of the load readings and guaranteed consumers' minima, he is in a position to adjust the load curve of the system according to requirements by issuing, from time to time, control signals, thereby reducing the supply to the controlled load of the system during periods of heavy uncontrolled load, and increasing it when the latter falls. Upon the occurrence of a cold snap the supply undertaking can thus determine the maximum demand that it is prepared to accept.

The following are a few recommendations as to the future attitude towards domestic electrification.

The ultimate aim can hardly be entirely to eliminate

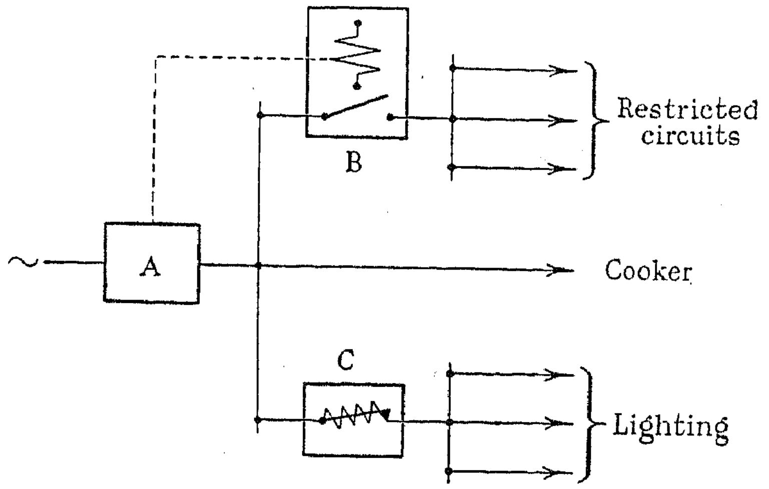

Fig. 3.—Circuit diagram of a consumer's installation equipped for centralized demand control.

A = demand limiter.
B = contactor.
C = miniature circuit-breaker.

the use of fuel in households throughout the country. On the contrary, there seems to be point in encouraging the use of coal in existing establishments—even for cooking and water heating—during the dark and cold season. The development of the domestic thermal load should be governed by the consideration that the domestic heat requirements constitute the only large-scale application of electricity that lends itself readily to off-peak storage. Taking the broad view, the aim should be by this means to raise the collective load factor of the national electrical generating and distribution system to twice its pre-war value. A Grid load factor of 70 % no longer appears Utopian.

As regards the individual components of the domestic thermal load, it does not appear necessary to aim at complete abolition of peaks in the cooking load, for, by temporarily reducing the collective water- and space-heating load, demand control is quite capable of dealing with residual peaks.

Electric water heating should on principle be on a thermal-storage basis. The water heater best adapted to the new system of control appears to be of the type operating at variable volume, the feed into the tank being so controlled that water is only admitted when the voltage is on, and the flow so adjusted that the water is immediately heated up to the required temperature, at which it is maintained by supplementary thermostatic control.

The greatest attention should be devoted to the problem of electric space-heating. It ought to be generally recognized that it is the indiscriminate and unrestricted use of radiators that will eventually prevent the price of electricity for domestic purposes from being lowered to, or maintained at, the level necessary for enabling this convenient form of energy to be used liberally and by everybody for cooking and water-heating.

Living-rooms may continue to be heated by coal fires in winter, the more so since the appearance of a fire is generally appreciated. There still remains plenty of scope for electric space-heating, for instance in bedrooms, where there is frequently no fireplace at all or where the lighting of a fire does not appear worth the trouble, and in living-rooms before and after the dark and cold season. For people who can afford thermal-storage equipment electric space-heating will remain available without restrictions as to place and time.

THE ELECTRICITY SUPPLY (METERS) ACT, 1936—ITS LEGAL AND TECHNICAL IMPLICATIONS

By Alwyn Evans, Associate Member.*

(Abstract *of a paper which will be published in August, in Part II of the Journal.*)

The Electricity Supply (Meters) Act, 1936, was brought into being through a dispute between two parties, Joseph and the East Ham Corporation. The former refused to pay his account owing to an alleged inaccurate meter reading, and as a result of legal actions in the County and High Courts a Bill was passed in Parliament setting up machinery to deal with the provisions made in Section 49 of the Electric Lighting (Clauses) Act of 1899.

The enactment related to the appointment of meter examiners and the duty of authorized undertakers to provide suitable meter-testing apparatus. It further stated that the existing meters on circuit were to be considered as "proper" meters, but would not afford conclusive evidence of electrical energy ascertained, and, therefore, required to be disconnected and certified within 10 years from the appointed day.

In 1937 the Electricity Commissioners appointed the examiners and also issued a series of publications. During 1938 the Minister of Transport fixed the 1st July, 1938, as the appointed day for the provisions of the Act. An important result of the Act is that an authorized undertaker would be able to disconnect the supply to a consumer if the latter refused to pay his account through disputing the accuracy of the certified meter installed.

An important implication of the Act which is essentially psychological in character makes it necessary to provide a laboratory atmosphere in the testing station. This is to ensure that the technical implications of the Act will more likely be carried out effectively.

The direct implications of the Act to the engineer were technical, and upon him rested the responsibility of carrying into effect the requirements laid down by the Electricity Commissioners in their memoranda relating to specifications and methods of tests. In their specification relating to wattmeters it was found necessary for every testing station to determine the magnitude of the self-heating error of each wattmeter. Owing to the various conditions imposed upon the wattmeters when in use, the corrections in the report of the National Physical Laboratory are given for "cold" conditions. This method makes it possible, within limits, to check the overall accuracy of the direct-current potentiometer, together with that of the sub-standard wattmeters. To ensure that the corrections are determined accurately under "hot" and "cold" conditions, it has been necessary to take many precautions, such as the elimination of electrostatic effect and the reversing of the applied voltage and current in order to obtain the mean correction. In the methods of testing it is stated by the Commissioners that the load on any sub-standard indicating wattmeter shall not be less than 40% of its full-scale reading. This is achieved by the use of a Class AL current transformer in conjunction with the wattmeter.

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* Aberdare Urban District Electricity and Transport Department.

The lay-out of the meter-testing station with which the author is associated is shown in Fig. 1.

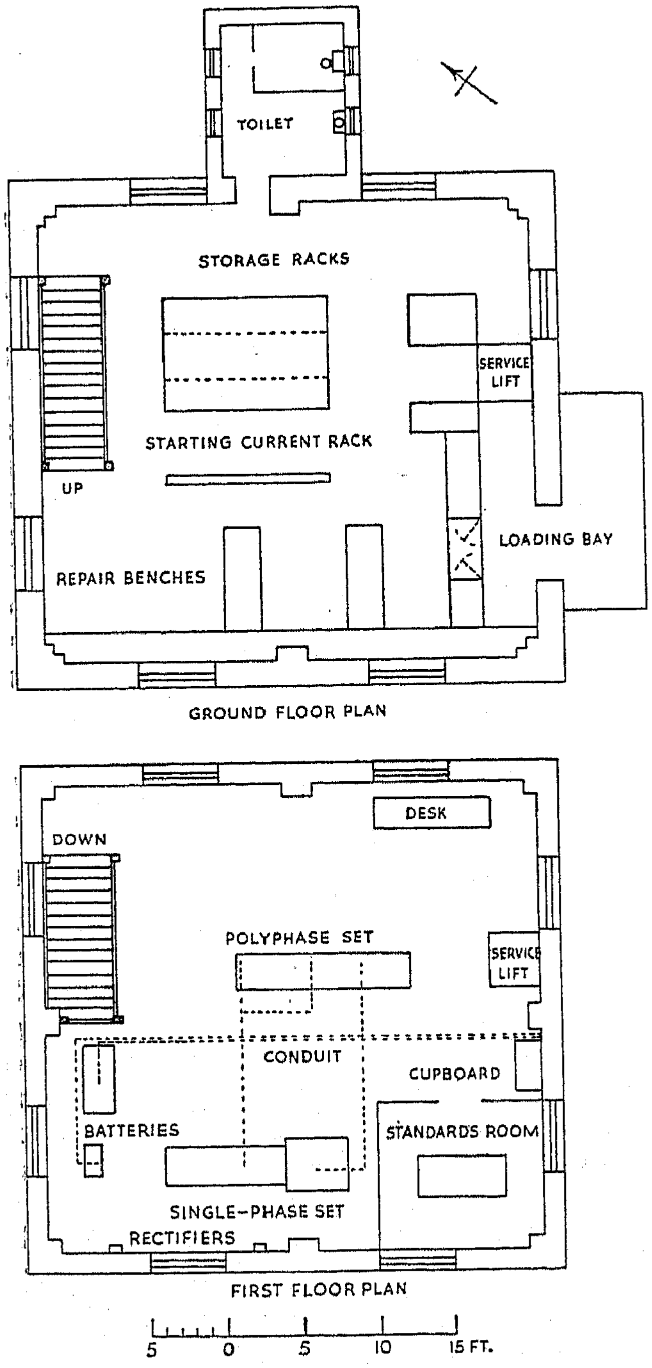

Fig. 1.—Layout of meter testing station.

The rotating sub-standards used are of a universal type because they can be commissioned for single-phase or polyphase working; they have voltage ranges of 400–230 volts and 230–110 volts with current ranges of 5 amperes. When used for single-phase testing, the current coils are placed in series with each other, thereby producing a higher torque which is so important at low loads. Each instrument has a dial for "revolutions tests" and also a kWh dial for long-period tests. The wide range of voltages makes it possible to work on the secondary side of a high-voltage metering equipment. In relation to the minimum load permissible on rotating sub-standards, the Commissioners stated a minimum figure of 25% of full load. This is possible by using the instruments in conjunction with Class AL current transformers.

For methods of testing, the Commissioners referred to three methods. Long-period dial tests using sub-standard rotating meters were dealt with under Method A, whilst the run-off method of testing was related under Method B. Lastly, the use of a sub-standard indicating wattmeter and stop-watch was specified under Method C.

The Commissioners in their specification for alternating-current control apparatus laid down only one condition. This was that the peak factor of the voltage wave-form should not be varied by more than 3%. Peak factor and form factor are not synonymous terms. The measurement of peak factor would involve the use of a special peak voltmeter or a thyratron potentiometer, neither of which is available in the majority of testing stations.

The polyphase testing equipment installed operates from the mains and is suitable for testing single-phase and polyphase meters with current capacities up to 500 amperes. It is provided with voltage and current transformers giving currents up to 100 amperes, whilst the extension is used for obtaining currents from 100 amperes up to 500 amperes. The multi-range current transformers have a Class AL accuracy with a rated burden of 7·5 VA and ratios varying from 0·5–500/5 amperes. Voltage control is effected by means of auto-transformers which give a variation from zero to a maximum of 600 volts. The transformers are arranged in such a manner that there is no influence on the wattmeter readings due to the magnetic fields set up. Prevention of any undue overloading of the precision current transformers and instruments is arranged by special switching, whilst for carrying out "balance of elements" tests a switch is provided for reversing the direction of the red-phase current. The three single-phase indicating wattmeters rest in an illuminated recess covered by a glass plate for protection purposes. The voltmeters, ammeters and frequency meter are first-grade instruments of the edgewise pattern mounted in a common case. All the regulating and loading transformers, together with the switches, are totally enclosed and only the operating handles are visible.

The single-phase equipment installed is used for testing meters with capacities up to 20 amperes at 230 volts. A precision current transformer is used for wattmeter operation, whilst the 3-phase supply is used to obtain a power factor of 0·5 lagging. Both single-phase and polyphase equipments can be interconnected with each other by simple switching.

Site tests in the case of disputed meters have been a matter of consideration by the Commissioners, but no details have yet been published relating to specifications of apparatus and methods of testing. If it became necessary to test a disputed meter, then a rotating sub-standard could be placed in commission with a single-phase phantom-load testing transformer which would provide steady testing currents.

A satisfactory method of transporting meters was found by making wooden boxes similar to trays, which could be taken out of the delivery vans and placed in the testing station for the daily changing of meters. The boxes were partitioned to take the various sizes of meters, and were then lined with Sorbo rubber. This provision freed the meters from undue shocks and vibrations during transit.

The testing station was designed to deal with 2 000 meters per annum. It was found that the average operating cost for carrying out the provisions of the Act in respect to single-phase quarterly and prepayment meters amounted to 4s. 2d.

THE RADIATION RESISTANCE OF SURFACES OF REVOLUTION, SUCH AS CYLINDERS, SPHERES AND CONES

By E. B. MOULLIN, M.A., Sc.D., Member.*

(ABSTRACT *of a paper which was published in March, in Part III of the Journal.*)

This paper develops formulae for calculating the power radiated by electric charges distributed on a surface of revolution. The method employed is that developed independently and almost simultaneously in 1929 by A. A. Pistolkors and by the present author. It consists in calculating the in-phase component of electric force at the surface of the conductor, due to any assigned distribution of harmonically pulsating current.

In the present work the current distribution can be completely general: the only simplification in the statement of the problem is that the current density at all points of the surface alternates in the same phase. In practice this is physically impossible, though in most cases the phase charge is believed to be small; it has certainly been tacitly ignored by all workers so far. With this *caveat*, the expressions derived are correct for any current distribution which may be postulated. The much harder problem of finding the distribution appropriate to the given conductor is not attempted; when this is solved it will be easy to take into account the phase change, which is ignored here.

A process is needed for calculating "back e.m.f." produced in an aerial—something comparable with the flux-cutting rules of the machine designer. The possibility of such a process is due to Lorenz, who succeeded, by the formulation of two new mathematical tools, the retarded vector and scalar potentials, in stating Maxwell's equations in a form that gives the electric field at any distance from a point charge which is variable with time. In effect this gives an enlarged and generalized statement of the inverse square law, and therefore must be competent to provide a complete expression for the force at the surface of a conductor. The author uses the Lorenz equations and finds that an alternating current produces an electric field in phase with itself and opposite in sense: this is the back e.m.f. against which the current has to work because, of necessity, it is radiating power.

The author has used this method in a previous paper to calculate the radiation resistance of thin wire aerials, both straight rods and aerials with extended or folded roofs. But the ever-increasing use of very short waves has brought into existence aerials which are not always thin wires and may often be cones, spheres or cylinders where the diameter is comparable with a wavelength.

The present paper derives general expressions for the "radiation voltage" of, and the total power radiated by, such bodies. It opens with the preliminary problems of calculating the retarded scalar potentials at any point due to two unlike charge elements separated by a distance $2z$, and the retarded vector potential due to two current elements separated by a distance $2z$; the first six terms of which are evaluated. These results are extended to deal with two coaxial circular rings of elements with parallel planes separated by a distance $2z$; for charge elements the charges are unlike, and for currents the elements are either parallel to the axis or radial thereto. Obviously these three investigations are the bricks from which can be built any surface of revolution with charge distribution symmetrical about the equatorial plane.

The solutions are applied to the particular cases of the circular cylinder, the cone and the sphere; but this is by way of example only. It then remains to derive numerical results appropriate to any charge distribution which may be assigned to these bodies; this is done for a cosine distribution, but there is no attempt to discuss whether this distribution is appropriate. The results are quite general and can easily be turned to practical use when more information is available about the distribution on cones and cylinders.

When the work had reached this stage the author had to discontinue it as he joined the Government service.

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* University of Oxford.

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